# ILLUMINATING ENGINEERING

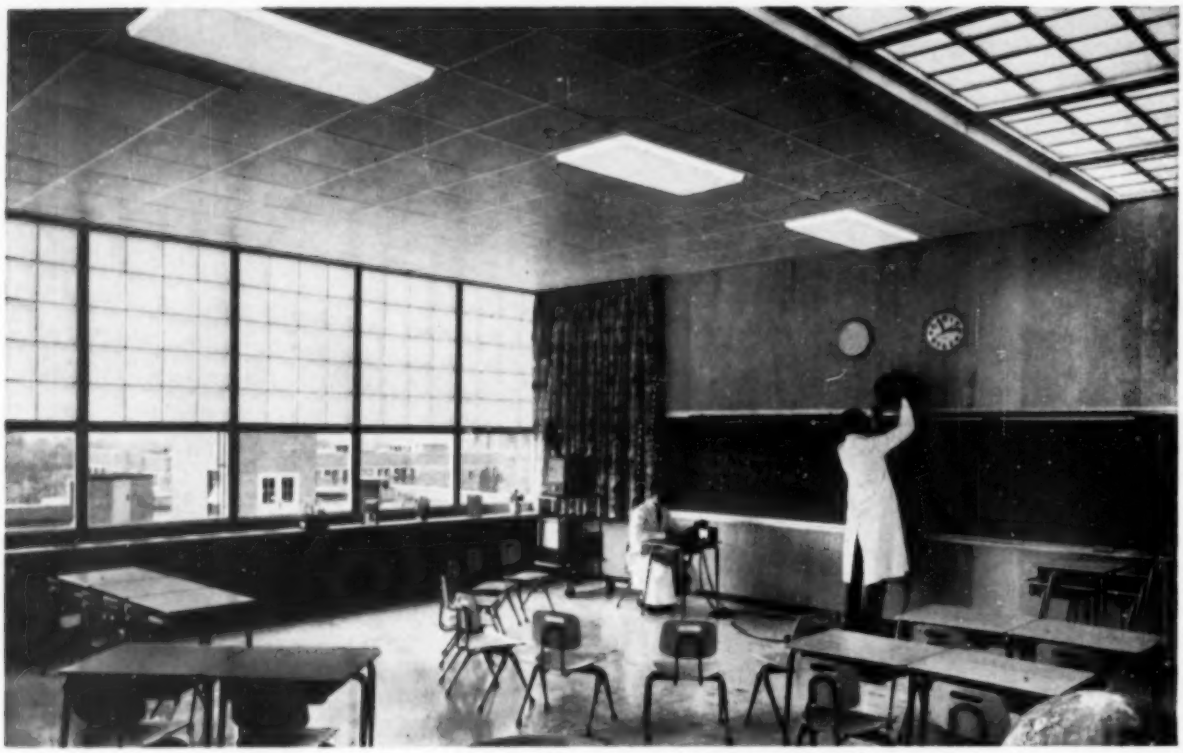
FEBRUARY 1954

•

*Featuring*

**Symposium on Light and Vision**

THE JOURNAL OF THE ILLUMINATING ENGINEERING SOCIETY



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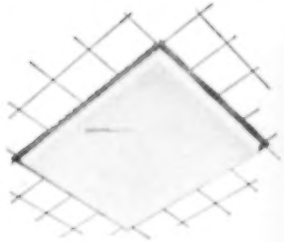

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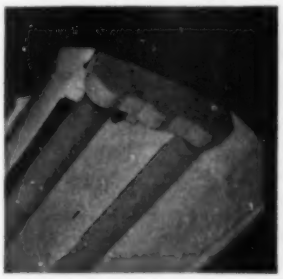

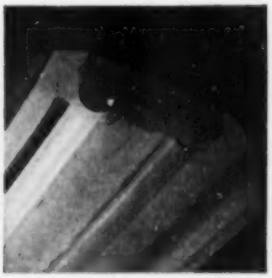

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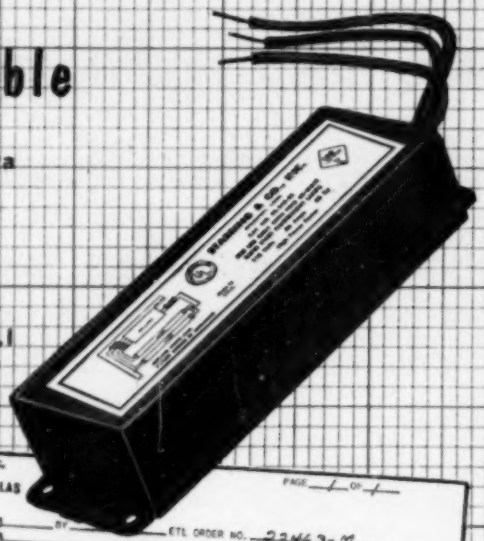

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THE JOURNAL OF THE ILLUMINATING ENGINEERING SOCIETY

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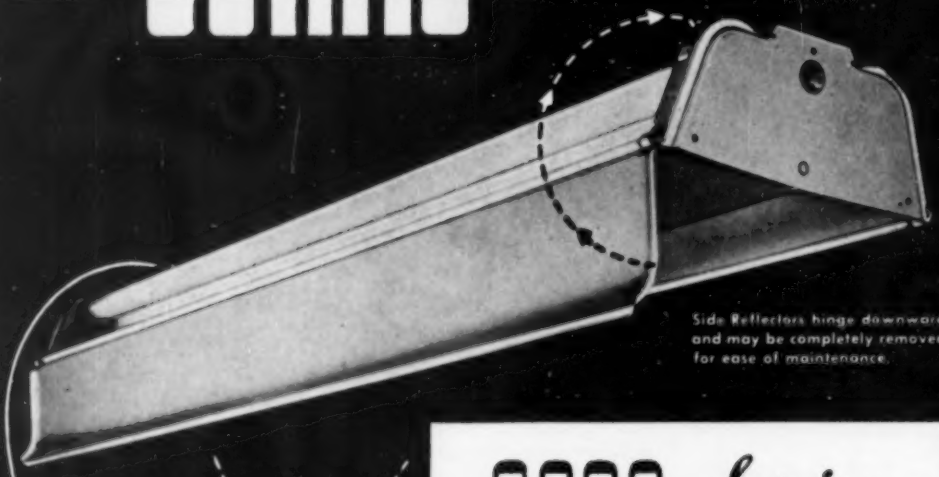

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# Symposium on Light and Vision

**A discussion by some eminent physicists on the researches and opinions now current in the field of vision and its relation to various aspects of illuminating engineering.**

**H. C. Weston**

## Visual Fatigue

REFERENCES to strain and discomfort in connection with seeing are to be found in some of the most ancient literature we have. Thousands of years ago, some of those early scientists whom we call philosophers described these sensations, and pointed out that among the causes of them are close intent vision and over-bright and wrongly placed lights.

In our own time much thought and experimental research has been devoted to these same subjects and to elucidating the conditions which are necessary for the avoidance of *unwanted* effects associated with the exercise of sight. It is comparatively recently, however, that much discussion has arisen concerning what is called *visual fatigue*. It seems to me to be very important that we should consider the utility of this expression and to what concepts it may be applied.

Strange as it may seem, the condition which we call fatigue — and which we all experience at one time or another — is not at all easy to define scientifically. Many definitions have been advanced, but all agree in regarding fatigue as a condition of *diminished capacity* for activity resulting from previous activity or at least as a condition which causes unwanted changes to occur in our pattern of activities.

My approach to the subject of so-called "visual fatigue" is on the assumption that when people say that the conditions of lighting to which they may be exposed are more or less visually fatiguing, they are thinking of fatigue in the ordinary dictionary meaning of the word, which is "weariness resulting from bodily or mental exertion."

How then can weariness or tiredness of sight come about, and what conditions of lighting can bring it about? These are the questions considered in this paper.

### Exertion in Vision

Vision certainly involves bodily and mental exertion, but its essential motor character is not suggested at all by the popular idea of vision as one of the five special senses. In fact, all these senses are motorized and most obviously, those of touch and vision. (Geo-Trum. Ladd.)

Sensations of light and color are the "stuff" of vision, but they must first be got and then "made-up" before what we understand as seeing is accomplished. The getting is done by a multitude of receptors housed in rotatable globes so that they can be turned as a body in various directions in search of the "stuff" of vision. This is by no means all of the movement in seeing: there is more that is either necessary or helpful, and which has more to do with so-called "visual fatigue" than is generally realized.

The "making-up" is the task of the brain. It is an activity about which too little is known, though it seems to be less costly of energy than muscular

A paper presented at the National Technical Conference of the Illuminating Engineering Society, September 14-17, 1953, New York, N. Y. AUTHOR: Director, Group for Research in Occupational Optics, Institute of Ophthalmology, University of London, England.

activity. Nevertheless, it is the physical basis of such mental exertion as vision entails. Although there is constantly activity of this kind in seeing, we get most of our visual perceptions without any awareness of mental effort. In adverse conditions, such as fog or dim lighting, seeing is accompanied by feelings of effort, strain and ultimately of fatigue which, for the most part, are referred to the region of the muscular parts acting in vision, which are, indeed, acutely tensed. Again, in the prolonged scrutiny of minute detail it is the visual muscles which are the most obvious doers of work, and it is the muscled eyes that are said to be tired by such a visual task.

### Sensations from Retinal Stimulation (The Visual Process)

There are many references in the literature to fatigue of the retina. Such a condition used to be described in the text-books of ophthalmology under the name "retinal asthenopia" (literally: asthenopia= weakness of sight). It was said to be a state of "exhaustion of the retinal sensibility induced by prolonged visual effort" (Clarke, 1892), or by "long hours of near work which has been done by artificial light" (Hartridge, G., 1900).

Its symptoms were paradoxical. Sometimes the acuity of vision was diminished, but it might be very good. There was photophobia, attributed to retinal hyperaesthesia, although if the retinal sensibility was exhausted there should be no intolerance of light but a diminution of light sense. It could be produced not only by bright lighting but also by "ordinary" lighting, as well as by candlelight. It was generally agreed that so-called retinal asthenopia occurred almost exclusively in persons whose "nervous system is exceedingly sensitive and unstable," that is, in persons of the hysterical or neurasthenic type. No wonder that it was "always troublesome and difficult to cure" (Hartridge, G., *loc. cit.*).

Parsons has pointed out (Parsons, 1927, 1943) that some, at least, of the phenomena of muscular fatigue appear to be due to the accumulated chemical products of metabolism, whereas the chemical changes which occur when the retina is stimulated are reversible, so that with physiological intensities of excitation, functional fatigue either does not occur or is very transient. "Eyestrain undoubtedly occurs, but there is no evidence to show that it is due to retinal fatigue."

Nevertheless, the retina is not just a mass of independent light receptors but a complex organ—actually a part of the brain — wherein nervous interaction occurs. It is, of course, subject to adaptation: but, as to fatigue, its occurrence is doubtful, although Adrian has conceded that it may not be altogether impossible. In any case retinal fatigue would be unfelt.

Although there is increased awareness of the eyes ("subjectivity in the eye") when "visual fatigue" is complained of, it is not from the state of the retina itself that this arises. Stimulation of the retina, whether normally by light or abnormally by a blow or pressure, gives rise to visual sensations and, as far as is known, to sensations of no other kind. In no circumstances can visual sensations become other-sensations, or even sensations of mixed type, such as luminosity-strain or luminosity-fatigue sensations. Even pathological states of the retina excite no feeling, so that their victims may notice only a general failing of sight, or a contraction of the visual field. A fatigued retina would yield weak sensations of luminosity, or faint vision that, for all the subject may know, might as well be the result of weak stimuli as of retinal fatigue.

### The Visual Muscles

Feelings of fatigue or tiredness, however, are the prompters of complaints of visual fatigue, so their basis must be sought elsewhere. As mentioned already, it is the activity of the various muscles used that appears to involve much of the energy expended in seeing. The non-visual sensory impressions derived from these muscles, from the eyeball itself (sensations of pressure or tension), and from tissues which are stretched or moved in the course of vision, seem to provide the sensory basis of the localized feeling expressed as "tiredness of the eyes," while, together with even more indefinite organic sensations, seemingly related to cerebral activity, they underlie the more diffuse feeling expressed as one of "visual fatigue." Hence attention needs to be directed particularly to the extent of the muscular activity involved in vision, especially in those circumstances which most often lead to complaints of visual fatigue.

In binocular vision no less than twelve muscles—six per eye — are involved in every movement and act of fixation of the eyes. These extra-ocular muscles are shown in Fig. 1. Four other muscles, two inside each eye, control the aperture of the eyes; these are the pupil constrictor and dilator muscles. Another two muscles adjust the curvature of the lenses according to the distance of the objects of regard, and another four muscles (two pairs) act to open and blink the lids of each eye. These *twenty-two muscles in all* are the strictly visual muscles. Though some of them act reflexly—that is, involuntarily — at least sixteen of them

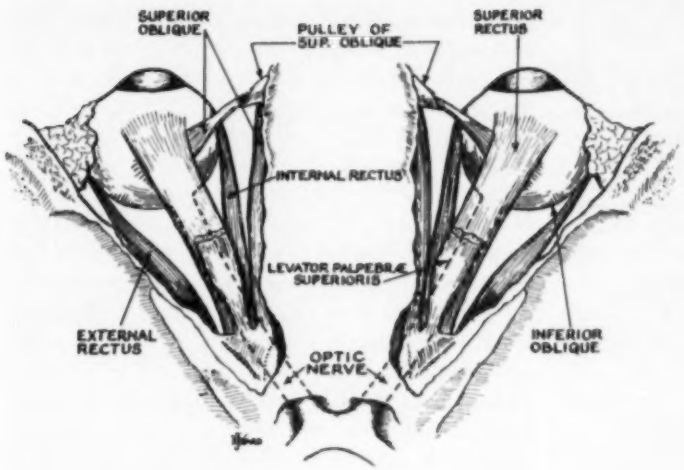


**Figure 1. The muscles which turn the eyes.**

are subject to voluntary control. They work not as independent units but in groups with delicately coordinated actions.

It is easy enough quickly to produce at will a feeling of strain and discomfort by action of the ocular muscles. Thus, an extreme movement of the eyes to the right or the left is so "fatiguing" that it soon becomes intolerable, and the unpleasant feeling lingers after the posture of the eyes has been changed. The feeling is elicited just as well if the lids are closed, so that any retinal contribution to it is ruled out. It is not wholly of muscular origin for such a movement entails pressures and tensions of other ocular connections. Similarly, if the eyes are converged to the near point of binocular single vision, a feeling of fatigue and a strong desire to relax the effort is not long in developing.

### Fatigue of Convergence and Accommodation

Two forms of fatigue occasioned by vision are recognized in ophthalmology, and both have to do with the eye muscles. The first form is fatigue of convergence. *This can occur only in persons capable of binocular single vision, since it is just for this capacity that convergence is required.* It cannot occur in the one-eyed and it is a fallacy to suppose that in them one eye has to do the work of two and is therefore more liable to fatigue. In orthophoric persons — that is, those having physiologically balanced oculo-motor apparatus — it does not occur unless protracted use is made of the eyes at very short range, or there is general fatigue which the ocular muscles will share. No kind of lighting will lead to fatigue of convergence in a situation which calls for little convergence, as when the only objects to which attention need be given are necessarily viewed from a distance of several feet; this is not to say, however, that fatigue of the extraocular muscles does not occur for other reasons in far vision. But when objects have to be seen for considerable periods, inadequate lighting may cause them to be viewed from too close a distance and this will increase the liability to fatigue of convergence. Inadequate illumination will make the viewing distance required for visual resolution shorter than it otherwise could be, although this is not the only defect of lighting that will tend to do so. No kind of lighting will suffice to prevent convergence fatigue in those who do *very fine* work, and there must be suitable rest pauses, or the degree of convergence used must be kept down by wearing prismatic spectacles (Weston and Adams, 1927-1929) or by the use of other optical aids (Weston, 1949).

The second form of ocular fatigue is that of the ciliary muscles, whose action accommodates the lens for distinct vision at different distances. In normal (emmetropic) eyes no effort of accommodation is required for seeing remote things, and very little is needed for viewing objects at arm's length. When therefore, the situation precludes a close approach to the objects of interest then, however these and their surroundings are lighted, fatigue cannot be due to excessive accommodation. If however, the lighting sufficiently degrades the contrasts in the scene surveyed, or (by veiling glare) in the retinal representation of it, accommodative effort may be made to obtain more distinct vision. Being ineffectual, it is doubtful if such efforts are persistent, but what does continue is *dissatisfaction* with the sensory data collected by the eyes, and mental effort in deciding what they represent; there is strain in forming a clear picture in the mind from a blurred picture in the eye.

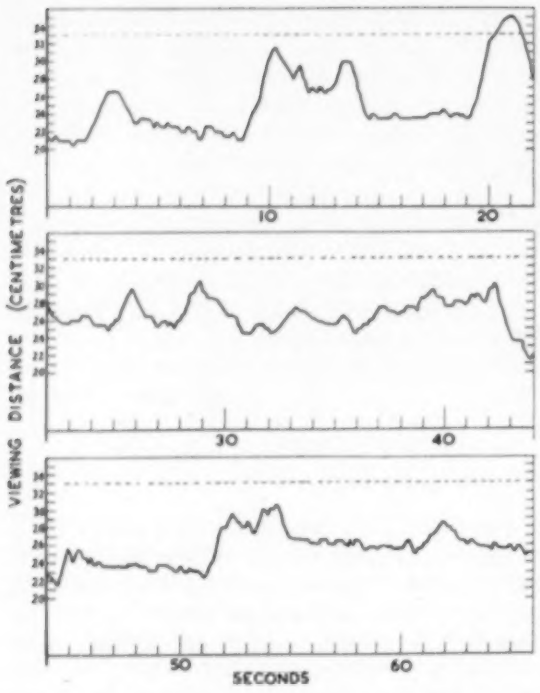


**Figure 2. Typical variation of viewing distance, and therefore of amount of accommodation and convergence of the eyes, during "close work." Task: tracing. Illumination about 10 lumens/ft². Broken line corresponds to ordinary reading distance, or accommodation of 3 dioptres.**

Accommodative fatigue, like fatigue of convergence, is due to excessively close work. Lighting is therefore responsible for this fatigue if it is such that it depresses visual acuity, and thus rules out a more reasonable viewing distance because the eyes could not resolve the smaller images they would then receive.

Accommodation is never held constant for long periods in near work, but is frequently varied, within limits separated perhaps by about one dioptre, even during short periods when the casual observer may notice no change in the worker's viewing distance. This variation is shown by photographic records of which Fig. 2, showing the records of a tracer is an example. Fatigue, when it occurs, is due to high average accommodation. Occasionally, persistence in near work will lead to a functional spasm of accommodation. The effect of this is to bring the far point of distinct vision closer to the eyes; that is to say, the condition is one of pseudo-myopia and there is blurred vision of distant objects. Since the advent of discharge lamps has made available a fairly wide range of composite lights, the possible influence of these different lights upon acuity and "visual fatigue" has been debated. Now the effective acuity, or capacity for discrimination of detail, depends not only on the prevailing brightnesses in the visual field but also on the definition of the retinal images, which it is the function of accommodation to perfect. With "white" or polychromatic lights the retinal images are always fringed, because of the inherent chromatic aberration of the eye. Therefore it has been thought that monochromatic light might give the best acuity, and also that spectral mixtures of the kind derived from some discharge lamps might make accommodation difficult. There is, however, no convincing evidence that for equal brightnesses near-monochromatic light (excepting perhaps, sodium) is superior to "white" light, and recent investigation (Solandt, White and Rosen, 1952) has failed to show any significant difference in visual acuity with a variety of illuminants, including fluorescent light, all of which were sensationally "white."

Besides this, Fincham has recently shown that the chromatic aberration of the eye is an asset rather than a defect. With ordinary composite lights the different color fringing which it gives to out-of-focus images according to the vergence of the light at the retina, provides a directional accommodation stimulus. That is to say, it "tells" a reflex sensori-motor mechanism which way to make the fine adjustment of accommodation — whether a little more or a little less curvature of the lens should be brought about. There is also another way — not yet fully elucidated — by which the vergence of monochromatic light at the retina stimulates the fine accommodation reflex. Fincham has suggested that this way may involve the Stiles-Crawford effect in conjunction with small oscillations of the eye while viewing an object. But he found that 50 per cent of his subjects did not accommodate without the chromatic stimulus which only a suitable mixed light can give. He has since found that fluorescent light provides this stimulus just as well as tungsten.

### Eyestrain

The two varieties of ocular neuro-muscular fatigue that have been considered are especially liable to occur in persons who have some uncorrected error of refraction, or some latent imbalance of the extra-ocular muscles (heterophoria), because abnormal neuro-muscular action is then required for good vision. The enhanced liability to fatigue due to such anomalies is the "weakness of sight" which is meant by the term "asthenopia." A too easily fatigued muscular system of accommodation,

**Figure 3. Some facial muscles active in vision. a. Frontalis; b. Corrugators; c-d. Orbital and Palpebral Orbicularis; e. Levator labii sup. nasi; f. Zygomaticus minor; g. Orbicularis Oris; h. Zygomaticus major; i. Depressor anguli oris.**

or, rather, one that has constantly to do more than its proper share of work — as in compensating for long-sightedness — is said to be the basis of what is called "accommodative asthenopia." Correspondingly, a muscular system of convergence that has the extra task of overcoming a tendency to squint is the basis of what is called "Muscular asthenopia," or "asthenovergence" (Stutterheim, 1937). Both varieties of asthenopia are frequently referred to as "eyestrain" but, because these anomalies sometimes exist without producing any symptoms, because there is no definite relationship between the severity of the symptoms when they do occur and the degree of refractive error or the muscle imbalance, and because the wrong glasses may cure some complaints of eye-strain and the right glasses may not, it has been held (Inman, 1924) that eyestrain is often an expression of emotional disturbance and is due more to a psychoneurotic disposition than to the action of the muscles governing accommodation and binocular vision. It is at least safe to say that emotional stresses and instability often decrease the tolerance of discomforts and fatigues. Moreover, there is no doubt that complaints of eyestrain or visual fatigue — whether the eyes, the work, or the lighting be held at fault — do come frequently from people who are highly strung, sensitive or of nervous temperament. A feeling of eyestrain can, of course, arise in normal sighted (approximately emmetropic and orthophoric) persons in the most blameless lighting if the task is such that the motor apparatus of vision has to be driven nearly "all out" for sufficient time. It can also arise from immobilization or restricted activity of the ocular muscles, as in prolonged concentration of the gaze or scanning of a small angle field, even if the field is not a near one and if its contents are plainly visible ("postural eyestrain," Weston, 1949).

### Other Muscles Involved in Vision

Only part of the total muscular activity subserving vision goes to the adjustment of accommodation and convergence. Ignoring the pupilliary muscles, which are not voluntarily controlled, the extra-ocular muscles are used for every movement of the eyes over the scene, as well as for keeping the eyes in particular postures when the visual occupation so demands. The eyelids must be kept open — sometimes by an effort strong enough to overcome the blink-reflex — and some of the facial muscles, shown in Fig. 3, as well as those of the neck, are involved as accessories in vision. Since critical vision is essentially an act of close attention, it can involve the whole voluntary neuromuscular system of the body, largely by way of inhibition, or "freezing," of all movements which might mean failure of the eyes to gather all the sensory impressions the mind needs to facilitate fine visual discrimination.

The dynamic and wholesale character of attention is not always sufficiently appreciated. But, that attention involves motor control of all the parts of the body that can be voluntarily controlled is evident especially in soldierly attention, and the word itself means "strained tight." Voluntary attention to visual, or any other, sensory presentations is the more fatiguing and difficult to sustain the more completely the muscular system and the mind is given over to it.

The diffuse fatigue that follows from the extensive bodily tenseness associated with intent vision can only be called "visual fatigue" if much of the whole organism is regarded as constituting the visual system — at any rate while voluntary attention is given only to vision, when we become, so to speak, all eyes. It is less open to misunderstanding, however, to speak of fatigue occasioned by visual concentration! When such fatigue is felt in connection with a dominantly visual activity, the feeling is sometimes attributed only to the eyes by persons who are not much given to analysis.

Figure 4. Involuntary change of head posture to limit angling of the eyes. Clerical work.

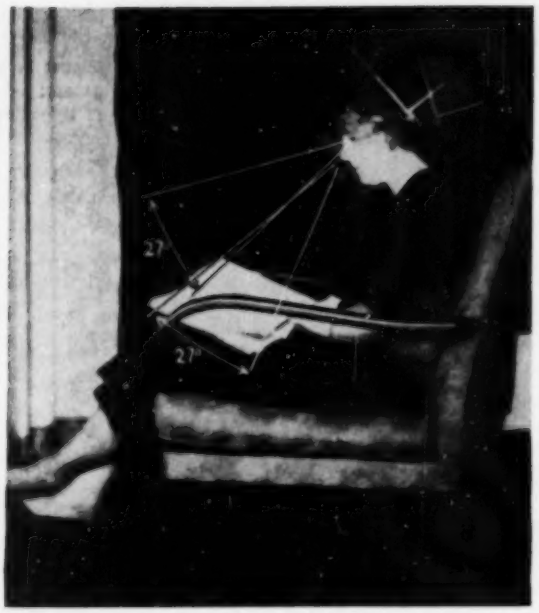


Figure 5. Involuntary change of head posture to limit angling of the eyes. Reading.

## The Posture of the Eyes and Head

The posture of the head necessitated by inadequate illumination of work-objects on benches and the like, and by the inspection of minute objects of this kind even if they are very well illuminated, has been condemned as a cause of fatigue by many who have interested themselves in the hygiene of vision. Two examples are the nineteenth-century oculists Cohn, of Germany, and Priestley Smith, in England, who campaigned for better lighting and better desks in schools.

In its natural position the head is erect and the plane of fixation of the eyes in the position of functional rest is horizontal, or nearly so. In almost every kind of work done at a bench, desk, table or machine, the work is below the standing or the seated eye height, so that the head is more or less inclined forward and the plane of fixation is no longer perpendicular to the frontal plane of the eyes, but is inclined downwards by exercise of the inferior recti, and the superior oblique muscles. Coupled with the effort of convergence, if near viewing is necessary, there is, therefore, the effort of maintaining the depression of the eyes, although the eye-muscles are such as to make looking down second only to looking straight ahead in point of ease.

The possible angular excursion of the eyes in the downward direction is limited to about 50 degrees. Photographic studies of a variety of workers show that they generally avoid depressing the eyes to more than about half this angle. If this is not sufficient to secure fixation of the work, bending of the neck and trunk takes place. The average downward rotation of the eyes found for operators who do their work standing is about 27°; for operators who work sitting the average eye depression is about 24°. Sometimes, owing to the location of the work, or to faulty habit of the worker, the downward angling of the eyes, instead of being limited to some 50 per cent of the maximum, is as much as 70 per cent, and occasionally, it is even more. Such an eye posture cannot be long sustained, and those who attempt it frequently complain of fatigue.

Fig. 4 shows a book-keeper at work while wearing a head attachment, which enables the vertical angling of the eyes to be measured from the photograph. Actually, two photographs have been superimposed to show how the eye and head depression changes when fixation is transferred from the top to the bottom of the page. The eye depression, which is nearly 60 per cent of the anatomical limit when working on the top line, is prevented from exceeding this value very much at the bottom line by an increase of 25 degrees in the depression of the head. The total effort required by the work is thus distributed between the ocular muscles and the muscles of the neck and shoulders; it would be

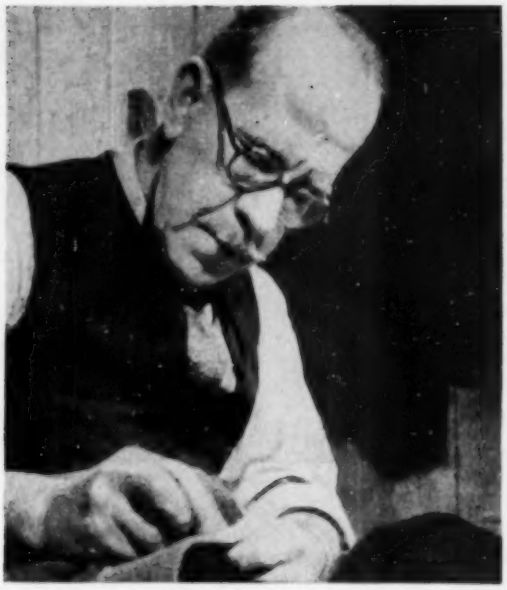

**Figure 6. Posture of the head to avoid undue depression of the eyes in tailoring; note also the knitted brows.**

**Figure 7. Posture of head and eyes when directing the gaze vertically downward.**

insupportable if required of the ocular muscles alone.

Fig. 5 shows the same person engaged in reading. Here there is greater freedom in choice of posture, and the smaller depression of the eyes is kept constant as the gaze travels from top to bottom of the page. To limit the eye depression to 27 degrees the inclination of the head varies through an angle of 22 degrees as the page is read.

In Fig. 6, although the depression of the tailor's eyes cannot be measured, it is evidently greater than the book-keeper's, owing to the position of the work. Evidently, too, the corrugator muscles are being used, as well as each orbicularis, and the exertion of these muscles, as well as those of the neck, contributes to such fatigue as the work entails.

Fig. 7 shows a worker whose plane of fixation is turned downwards through 90 degrees from the normal. But only 23 degrees of this depression is achieved by a rotation of the eyes from the primary to a secondary position, the remaining 67 degrees being due to bending of the neck to the fullest extent, and to bending the trunk. This extreme measure to limit the fatigue of ocular depression is evidently thought to be worth while on the whole, but the posture is one likely to impede the ocular circulation and to favor the occurrence of some of the well-known symptoms of "tired eyes."

Quite different are the conditions for hosiery linkers (Fig. 8). Here the fixation point is only slightly below eye level when the worker's head is erect. There is no fatigue due to neck bending or eye depression, but the viewing distance is short, thus involving considerable accommodation and convergence.

**Figure 8. Arrangement of machine and operator's seat to place the work at eye level. Hosiery linking.**

**Figure 9. (left) A striking illustration of the expression — and permanent wrinkling — produced by contraction of the facial muscles for intent vision in very bright surroundings.**

**Figure 10. (right) Expression due to contraction of the grief muscles on exposure to glaring photographic studio lights.**

### Muscular Reaction to Glare

The muscles of the lids — the levator and the orbicularis — the corrugators, the frontalis, and sometimes the muscles of the cheek and upper lip, are associated with vision — either habitually or under particular conditions of field brightness. Darwin's well-known work on the expression of the emotions, contains an excellent account of his careful observations on the use of the facial muscles during intent vision, particularly in bright surroundings. He pointed out that, when striving to distinguish a distant object in broad daylight, it is the almost invariable practice to contract the brows to prevent the entrance of too much light, the lower eyelids, cheeks and the upper lip being raised at the same time to lessen the orifice of the eyes. These muscular contractures are strikingly exemplified in Fig. 9, which portrays a very old woman, so long accustomed to make them that they have permanently lined and furrowed her face. The feeling of strain in seeing is much augmented when the facial muscles have to be used in this manner.

Some of the muscles which act together to produce the obliquity and drawing together of the eyebrows, which is so characteristic a feature of the expression of grief, anxiety or distress, are known as the grief — or the trouble — muscles. As a rule they come into play involuntarily. Fig. 10 shows them in action expressing the distress occasioned by the photographer's glaring lights, because the boy is trying to see in detail instead of gazing without purpose in the direction of the lights.

The contribution these contractures make to the felt fatigue associated with seeing can hardly be called in question, and they are undoubtedly among the causes of frontal headache, which is often one of the symptoms of those who complain of eyestrain. (Parsons, 1910).

The conditions of lighting in which these photographs were taken would be considered intolerably glaring in an office or a factory, but it is important to recognize that the discomfort and fatigue they cause depends a good deal on what the seeing mind is trying to get from what confronts the eyes, or, in other words, upon the set visual task. Actors on the stage, and in the cinema and television studios, face blazing lights, but their visual task is not an exacting one — they have only to look in the direction of the audience, or the camera, without attempting to discern anything in particular — and they rarely show any signs of glare. Of course, even if they were distressed by the lights, their business demands that expression of their discomfort be inhibited, but it is probably true of actors in general that, because they make no mental effort to make out detail, they do not experience such discomfort and fatigue as others would in similar lighting. One artiste questioned by the author felt more comfortable when looking sourcewards rather than out of the spotlight beam. Here, the surrender to the fixation reflex — which is actually desirable — avoids the voluntary effort required to override it; this effort is a chief source of the fatigue which others often experience in the presence of glare sources.

The effect of varying the visual task on the expression of effort and distress caused by glaring lighting is shown by the four photographs in Fig. 11. The subjects were exposed to a 250-watt photoflood lamp in a 10-inch diameter silvered reflector

set about four feet away. The fixation point was about 9 degrees below the center of the glare source. The subject first looked at a patterned field and was asked to distinguish its details; then a blank field was presented so that no discrimination was needed or possible.

### Frowning

The simple frown so often associated with attentive vision is due chiefly to the action of the corrugators unopposed by the action of the central portion of the frontal muscle. The frown can be seen in Fig. 12 and, in this example, it is expressive of the difficulty in seeing to thread the needle on account of the tailor's presbyopia. Persons blind from birth have practically no voluntary control of the corrugators, so that, as shown by Fig. 13, they usually do not frown when the mind in intently occupied, though blinded persons, as Fig. 14 shows, may continue to do so by force of habit, although it no longer serves its original purpose.

Darwin pointed out that there is an analogy, as far as the state of the mind is concerned, between intently scrutinizing some object and pursuing an obscure train of thought, and the habit of frowning which is practiced as an aid to the one activity is carried over to the other for which it is not needed. Frowning is not, therefore, necessarily indicative of any real difficulty in seeing even when it occurs while a person is engaged in some visual occupation. It may occur when the lighting of the work is good as well as when it is bad, either from habit or because the work is troublesome to the mind aside from its visual aspects. On this account, measurements of forehead muscle action potentials may be unreliable for the purpose of detecting the effect of different lightings on the effort required for visual tasks, though some investigators have tried this method.

**Figure 11. The expression accompanying intent visual inspection in the presence of a severe glare source (left) contrasted (right) with the expression under the same conditions during casual seeing.**

**Figure 12. The frown shown here is indicative of difficulty in seeing to thread a needle, owing to the tailor's inability to focus the eyes for nearer vision.**

**Figure 13. In persons blind from birth, frowning is unserviceable and usually does not occur when the subject is intently occupied.**

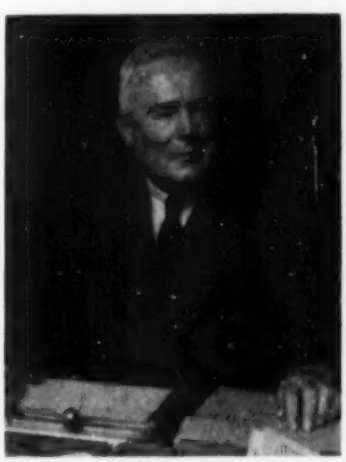

**Figure 14. The association of frowning with seeing is shown here by the persistence of the habit in mild form in this blinded man.**

### Elevation of the Eyes

It is well known that to maintain elevation of the eyes is more rapidly tiring than to keep them depressed. To do this, the levator, the superior part of the orbicularis, and, sometimes, the frontalis are in action, in addition to the oculo-motor muscles. It is the posture of the eyes, more than the brightnesses in the visual field, that accounts for the eyestrain and tiredness often experienced by people who occupy the front seats in cinema theaters: and it is for this reason that these seats must, by regulation* be sufficiently distant from the screen to render extreme elevation of the eyes unnecessary. Fatigue of the eye elevating muscles has also been held to be one of the causes of miner's nystagmus, and the oscillation of the eyes from which this complex condition gets its name is most readily elicited when the sufferer elevates the eyes. Especially in near vision, the effort to maintain convergence is considerably greater when the eyes are elevated than when the visual axes are in the horizontal plane or are inclined downwards. Hypnotists have often taken advantage of the fact that fixation with the eyes elevated is quickly tiring to the visual muscles, and, by leading to closure of the lids and exclusion of visual stimuli, facilitates induction of the hypnotic state. A tendency to sleepiness, or the relaxing wandering of the gaze, in schoolchildren who are called upon to sustain an upward gaze at chalkboard, wall-diagrams or the teacher, is partly due to this fatiguing eye posture. Obviously the postural factor cannot be eliminated by lighting.

### Visual Boredom

Different brightness distributions and different general levels of field brightness, besides affecting visual discrimination and the feeling of effort or of ease of seeing, are sometimes said to be soporific. Consider first an objective field of low average brightness. The effect of this is to narrow the field of consciousness by almost obliterating or greatly subduing much of the detail that otherwise would provide variety of visual stimulation. But variety is more than the spice of life; it is the *sine qua non* of conscious life. When sleep is desired it is wooed by excluding, or attenuating, as many sensory stimulants as possible. So, when there is no particular visual activity to perform, *e.g.*, when listening to a sermon or lecture, the "dim religious light" often supposed to be adequate for the purpose, favors sleep and is said to be soporific. But sleepiness then is not due to fatigue but to subdued visual activity, as well perhaps, as to ennui induced by a droning speaker. The effect is quite different when the need for visual discrimination is strong. Then, the dim lighting is frustrating, the mental effort of cognition is considerable and wearing, and there may be acute consciousness of the muscular effort involved in the necessary adjustments of the eyes. This is exemplified in night-driving without adequate lighting. So the same lighting can induce sleepiness or fatigue—which are different states—according to circumstances.

Indirect lighting is also said by some people to be soporific. Now the special feature of this lighting, when installed generally, is approximate uniformity of illumination over the "working plane" and softness of shadows. If it is used in an interior with pale-colored walls, the brightness of the environment may be monotonously even and boring. Boredom is not fatigue; it more resembles adaptation. It is a state of disinterestedness, characterized by inattention and by a feeling of weariness quite different from the feeling of fatigue due to muscular and mental exertion. If unrelieved, it induces sleep. In visual boredom there is no diminution of functional capacity, only a feeling of being "tired (or sick) of the sight of." Now, as Adrian (1947) has remarked in discussing the alpha rhythm of the brain, which is associated with the inattentive state, "It is difficult for us to be quite inattentive to what is before our eyes . . . but it can be made easier by looking at a uniform screen with nothing on it to catch the eye." Yet some exponents of what it is fashionable to call "brightness engineering" have suggested that ideal seeing conditions exist when there is substantially a uniformly bright visual field. This suggestion is insupportable on psychological grounds.

Even when there is a sufficient brightness diversity in an artificially lighted interior to prevent rapid visual boredom, there is one inherent feature of modern lighting that seems less desirable than it is usually assumed to be. This is its constancy — a feature which has so often been extolled and said to give artificial lighting some superiority over fickle natural lighting. But, however desirable constancy may be for critical visual tasks, it is a deadening feature of general artificial lighting. Whatever the brightness ratios may be within the objective visual field, they never change. Look anywhere and, time after time, what is seen has on each occasion its own unvarying brightnesses — absolute and relative — which become "familiar even to boredom." But daylighting is "alive": not only the absolute brightnesses but their ratios change, and the changes gratify the craving for variety which is fundamental to vision and all the senses. The achievement of "ideal" static brightness ratios will

*The Regulations made by the London County Council in this matter are based on the recommendations of the I.E.S. Committee on Eyestrain in Cinemas, published in 1920.

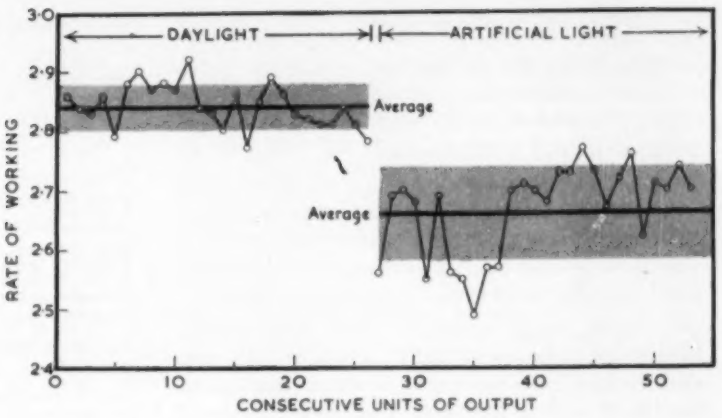


**Figure 15. Graph showing the deterioration of performance of inspection of cartridge cases due to dazzle from the work-objects in unsuitable artificial lighting.**

not bring artificial lighting to life; what is needed, however impracticable it now may be outside the theatrical field, is some method of making lighting suitably variable though constantly adequate. Perhaps in no other way will continuous artificial lighting be made as universally endurable without complaint as daylighting is.

### Distracting and Confusing Brightnesses

Any conditions of lighting which tend to distract the gaze from whatever should be its object are likely to cause annoyance and to intensify the feeling of effort or strain in maintaining attention to the necessary visual task. The most familiar distracting condition is the presence of bright light sources which are sufficiently intrusive in the peripheral field to call for inhibition of reflex phototropic movements of the eyes. An extreme example is the headlight of an approaching car at night. The effort required of anyone driving in the opposite direction to keep the gaze away from the blinding light, and to the near side of the road, is considerable, and it is undoubtedly muscularly and mentally fatiguing. In this example, the effect of the bright light is quite different from its effect in the theatrical example, because the vehicle driver has a critical visual task to do.

Visibly flickering light sources also cause fatigue, partly for the same reason, and partly because periodic fluctuations of illumination due to such sources may cause visual confusion and difficulty in maintaining fixation. It is well known that the use of unsuitable, or unsuitably placed, light sources for work involving inspection of shiny objects may cause persons to be dazzled by their work objects. If dazzling occurs, the work is described by those who do it as "more difficult" and "fatiguing." Fig. 15 illustrates this (Wyatt and Langdon, 1932); due to dazzling by polished brass cartridge cases, the time per unit of output became more variable than in diffuse lighting, and the average rate of output fell by about 7 per cent.

### Self-Control of Fatigue

Finally, the tendency to ration "felt ocular fatigue" in visual occupations may be illustrated in Fig. 16, which is based on a time study of several "fine" operations. Here the periods of intent and very close vision are followed by periods of ordinary vision, and these are succeeded by periods of casual and distant vision. The duration of each of

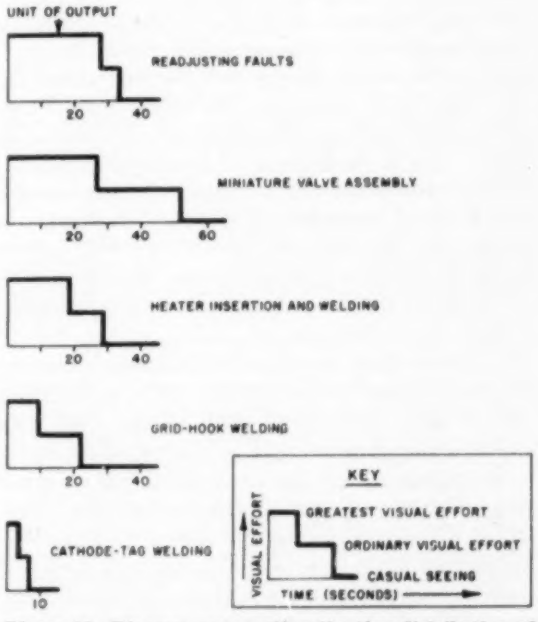


**Figure 16. Diagram representing the time-distribution of visual effort in five industrial operations.**

these periods is different for each operation performed, though the duration of each phase of the respective seeing-cycles is usually similarly proportioned. Usually not more than half of the cycle-duration is spent in fatigue-inducing vision. These studies refer to good lighting. Under adverse conditions more of the visual activity may be unproductive, or more productive of mistakes, but there may be no greater total expenditure of energy than there is under conditions of lighting which allow this energy to be expended more productively. Most people energize at their maximum only occasionally and, under strong motivation. Habitually, they work well within their physiological capacity and, by taking suitable "rest-pauses" — either voluntarily, whenever a feeling of fatigue arises, or involuntarily — they avoid undue fatigue. This is just as true of working with the eyes as with other workable parts of the body. Because neuro-muscular fatigue of the ocular apparatus is usually not allowed to become cumulative during ordinary spells of visual work, attempts to demonstrate it by seemingly appropriate tests, applied before and after the work, have generally failed. Unmistakably bad conditions of lighting and "forced labor" of the eyes are required to induce it prematurely in persons who have no optical or neuro-muscular defect.

## Conclusion

Summing up, "visual fatigue" may be defined, in terms of the ordinary conception of fatigue, as "weariness resulting from the bodily and mental, exertion of seeing." The expression "visual fatigue" may not be worth having on these terms, but, in any case, more precisely descriptive expressions ought to be used whenever reference is intended to fatigue due to the exercise of particular functions. Some such expressions have been mentioned in this paper, *e.g.*, "convergence fatigue." It has been made clear that those elements of the body neuro-muscular system which are directly associated with the eyes are not the only ones at work in attentive vision.

In such vision, exertion of the whole voluntary neuro-muscular system of the body may be involved and, accordingly, the fatigue that may ensue, although occasioned by looking, is general.

Conditions of lighting which are sub-optimal for particular visual tasks accelerate the onset of fatigue occasioned by seeing, chiefly because they necessitate undue muscular exertion in getting the required visual information, but also because they necessitate undue mental "exertion" for the processes of interpretation and discrimination.

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## DISCUSSION

WARD HARRISON*: In this afternoon's list of discussants, we begin to see some of the fruits of our investment in the I.E.S. Research Fund. All but one of those who follow me will give us some of the results of his research under the aegis of the Fund. Also, the Fund, I believe, made it possible for the Society to have Mr. Weston with us today, so that we may gain the benefit of a first-hand picture of the very fundamental work he has been doing in England.

One of the fine things about our work in lighting is that it draws together people with a common interest but different viewpoints from many countries. It has been my good fortune to attend some of the conferences of the British Illuminating Engineering Society and your Papers Committee has suggested that I give you some very brief facts about this Society and how it operates.

The British I.E.S. was formed a year or two after ours and it now has a membership of about 2500, or in proportion to population, somewhat better than ours. A rather

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astonishing fact is that their membership just about tripled between 1938 and the end of World War II. Approximately 30 per cent of their members are in or near London, and the rest are affiliated with one of the 25 "centers and groups" in various parts of the country — sections and chapters, I presume we would call them.

I am always impressed by the European viewpoint and the thoroughness with which they go into each subject under discussion. In a half day's session of the British Society, they never have more than two subjects listed for discussion; in fact, often only one, and that means that there is really time to go into the subject and the chairman doesn't have to look at his watch and say "we're already behind schedule and there will be opportunity for only one discussion of this paper." On the other hand, there are numerous and pointed discussions in England and if any errors exist in the author's reasoning, they will quite probably be brought to light. I am inclined to the opinion that the British get more out of one or two papers per session than we do out of five.

Again, I hope you will take no offense if I say that the British, in proportion to its size, seems to have a larger number of men interested in fundamentals than we have here. The names of Weston, Stiles, Lythgoe, Wright and Hopkinson, for example, are known almost as well on this side of the Atlantic as in England. I understand that this afternoon several discussions will bear on the presentation which Mr. Weston has just given us. Dr. Stiles' paper intrigues me because it upsets some of our recognized facts of lighting particularly in the realm of color — much as the theory of relatively upset the older physics. We are, indeed, fortunate to have the opportunity of considering two such worthwhile overseas viewpoints as have been presented to us today.

WILLARD ALLPHIN*: As is perhaps inevitable in such a complex field, Mr. Weston's thought-provoking paper asks more questions than it answers.

His summation that, "Visual fatigue — (is) weariness resulting from the bodily and mental exertion of seeing," helps to guide our thinking, but it does not hold out much hope for the development of a measurement technique.

We know that a particular performance may leave us feeling "tired" at one time and not at another, so it seems evident that such factors as motivation and general physical condition may affect the results. This would indicate that an attempt to measure "exertion," "effort" or "energy expenditure" would be more profitable than trying to measure "fatigue," but one quails at the thought of trying to measure "mental effort." Perhaps we can make a beginning by learning how to measure only the physical effort in seeing, and then provide the illumination which will permit good performance with least physical effort.

R. W. MCKINLEY**: It was a great privilege to hear Dr. Weston present his paper on "Visual Fatigue" at the National Technical Conference and I have since given much thought to aspects of Lighting related to "Visual Fatigue" to which I must confess I had not given much previous attention. Perhaps I should preface the following remarks and questions by saying that they are prompted more by a concern for means of providing comfortable environments, so classed subjectively by inexperienced observers, rather than of reducing fatigue regardless of how it may be defined or measured.

Some slight personal experience makes me appreciative of the fact that one may be quite comfortable on a well lighted stage. I believe Dr. Weston stated that this was because the actor does not attempt to carry out any demanding visual tasks under these circumstances. My question is, do you feel that the actor's ability to adapt his own comfort standards to suit his visual problems is something that could be developed by the average person under less severe conditions.

Though I believe it has oft been reported that the variety associated with daylighting as compared with electric lighting is appealing to most people, I believe that this prediction that this variation might in the future be built into electric lighting systems is the first by a responsible authority that I have heard along these lines. As the opposite view is rather strenuously supported in the United States, at least at the commercial level in the lighting industry at the present time, strenuous efforts are made and considerable sums expended for the prime purpose of minimizing this fundamental characteristic of daylighting.

I wonder if he could tell me and explain the basis for his comments what he considers to be the desirable aspects of the variability of daylight and if possible suggest any means for determining the desirable magnitude of change and the desirable rate of change which accounts for the favorable human reaction.

H. C. WESTON*: My thanks for Mr. McKinley's interest in my paper on "Visual Fatigue," and, particularly, in my seemingly heretical suggestion that constancy in artificial lighting may be a false ideal.

His first question is whether I feel that the actor's ability to adapt his own comfort standards to suit his visual problems is something that could be developed by average persons under less severe conditions. My answer to this is yes, providing the conditions in question are recognized as necessary and unavoidable rather than as being imposed arbitrarily or needlessly. There is an old "tag" that "What can't be cured must be endured," and I believe that this "philosophy" is one of the factors which influences the establishment of individual and group comfort standards. Such standards are also dependent on the range of conditions of which the individual has had some experience, so that if, for example, he has only experienced what others might describe as bad and indifferent artificial lighting, he may well come to regard the indifferent as comfortable. There can scarcely be any doubt that many people of the previous generation "felt comfortable" under conditions of lighting which some of us today would condemn as uncomfortable.

With regard to my suggestion that even "good" modern artificial lighting does not seem to be wholly acceptable as a day-long substitute for natural lighting, and that one of the reasons for this may be that artificial lighting creates an environment which becomes boring because both the illumination and the brightness distribution are invariable, I will try to be a trifle more explicit. In the first place, however, I should admit that my suggestion had no experimental basis, but was made after a close analytical consideration of the characteristics of artificial and natural lighting respectively, which left me unsatisfied that their difference in acceptability (which certainly exists for many

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**Pittsburgh Corning Corp., Pittsburgh, Pa.

*Author.

people) can be accounted for by any significant difference in their purely physiological effects during prolonged use. However, two psychological objections to artificial lighting deserve consideration. The first arises only when general artificial lighting is used as a permanent substitute for, or supplement to, natural lighting, and it has been disclosed in the course of numerous inquiries I have made into the causes of complaints about artificial lighting. This objection—though seldom clearly formulated—is fundamentally "ideal." It amounts to an idea of deprivation of natural light, to which one is "naturally" entitled, accompanied by a vague feeling of resentment of the artificial lighting—really because it is "unnatural" and is not imposed upon others who are fortunate enough to occupy interiors which normally receive adequate daylight.

The second psychological objection is the one I have raised, namely, that because it is static artificial lighting is necessarily monotonous, in that whatever brightness pattern it gives to an interior this pattern never changes; so that each and every element of the pattern looks just the same every time the gaze encounters it. I have never found this objection explicitly stated, but I believe it is implied in some complaints of premature "tiredness" alleged to be induced by certain artificially lighted environments, and I suspect that it underlies a number of more indefinite complaints. It is as if the sun always shone from the same direction and with the same intensity—a condition we cannot actually experience for long, but one we can scarcely imagine without also thinking how monotonous it would be; or as if the sky was always so uniformly overcast as to prevent any changes in the distribution of light and shade over the field of view. As a matter of fact, we do have experience of prolonged overcasting and we find it disagreeable—not because there is insufficient illumination for easy seeing, but because it seems "lifeless" and "dull," *i.e.*, lacking in variety.

Of course, as the gaze explores an environment there is variety of visual stimulation with any static non-uniform brightness distribution. Nevertheless, there is lack of variety in the sense I have already mentioned, namely, wherever the gaze dwells the particular brightness distribution and the actual photometric brightnesses encountered are what have become boringly familiar by reason of numberless previous experiences of them. On the other hand, in a daylighted interior, the brightness characteristics of the view in any given direction are not precisely the same hour after hour and gaze after gaze. The change may be slow—and imperceptible within any brief period of observation—nevertheless, the shift of brightnesses is sufficient to ensure that while "the set" remains unaltered it looks subtly—though, sometimes, very distinctly—different at different periods of the day. The "scene" is, so to speak, luminously plastic, and has from time to time a certain freshness of appearance whereas, with modern general artificial lighting, it becomes a "still" which—whatever its aesthetic merit may be—induces satiety sooner than does the "same" picture which "changes its expression," either continually with the "flow" of "living lighting," or at fairly frequent intervals with discrete changes of flux distribution.

Of course, becoming bored with an unchanging brightness distribution—even with one that is at first highly acceptable and pleasureable—depends on how much attention the environment receives and, thus, on the occupation of its experients. If one is generally absorbed in some activity the sameness of the environment may go unnoticed, but if—as in many occupations which are largely "automatic"—the environment is frequently surveyed its sameness—even if not explicitly appreciated—is the more likely to engender boredom.

As to ways and means of achieving artificial lighting which is "suitably variable though constantly adequate," I have no doubt that the ingenuity of lighting engineers will be equal to the task of devising them if the need is admitted.. And, incidentally, although the chief purpose of variability as exploited in luminous advertisements is doubtless to attract attention, it will probably be agreed that such signs are not so quickly boring as those which are luminously static.

In any case, I think the introduction of variability will need to be accomplished by a supplementary lighting system. That is to say, there should be a basic installation of static lighting which will ensure constant adequacy of illumination for the tasks ordinarily to be carried on in a room, and there should be an additional installation capable of providing a superimposed and variable distribution of flux, chiefly over visible surfaces of the interior other than those in the working plane.

In a small room, the additional "life giving" installation might conceivably consist of a single luminaire equipped with a slowly rotating system of reflectors or filters. The rate of change of distribution would need to be too slow to be distracting, yet sufficient for the "surround" to appear differently brightened if the gaze dwells on them at intervals of, say, 15 to 30 minutes. The change in distribution should preferably be a rhythmic. Alternatively, the supplementary installation might also be one for static lighting, and be operated at will by the room occupant if and when he "tired" of one particular distribution. This amounts to a multiple light-source installation wired and switched for several combinations, each of which would deliver a satisfactory working illumination.

It seems obvious that the use of desirable variability, as contrasted with the fortuitous and often undesirable variability associated with early artificial lighting systems, will be regarded as a luxury as, indeed, it rightly may be for interiors which have to be artificially lighted only during a few working hours. But the suggestion I made, both here and in New York, had reference to artificial lighting when, of necessity, it is used continuously as the sole, or the only significant, means for illuminating "working" interiors.

I feel that preoccupation with the study of static features of lighting, *e.g.*, desirable values of illumination, brightness ratios, etc., has tended to a neglect to elucidate all the features of lighting which may be important on psychological grounds, and I hope my suggestion for controlled variability of brightness distribution may stimulate some experiments to assess its value.

W. S. Stiles

# Visual Factors in Lighting

IN RECENT years there has occurred a gradual but well-defined change in the objectives of the illuminating engineer, particularly when he is dealing with interior lighting. Interest in revealing power continues. Lighting to see things must always remain a basic aim, but the emphasis is on characteristics of the lighting which have no immediate effect on the ability or otherwise to carry out a particular visual task, although in the long run an effect on visual performance may result. Evidence of this trend is to be seen in the attention given to certain aspects of colour — colour-rendering, colour adaptation and colour amenity — in the increasing importance attached to seeing objects and architectural features in the round, and in the efforts made to design lighting which is not only free from glare but is also visually comfortable or even, according to some circles in Europe, positively pleasurable. These developments make new demands on our knowledge of the properties of the eye and of vision. It is not sufficient to have information about the eye's ability to see the detail or contrasts of a flat pattern in black or grey and white, occupying a small central area of the visual field. We require to know more about the response to colour, much more in fact than ordinary colorimetric theory provides, and the visual effects of light in the outer parts of the field must be better understood. With the greater emphasis on appearance rather than on performance all aspects of the brightness concept are of special interest. In this paper some visual properties and visual concepts are reviewed which are known to have a bearing on problems of illuminating engineering, or which are likely to be relevant in the future development.

## Retinal Illumination and External Brightness Distribution

Brightness enters into problems of vision in two distinct ways. The first of these is most easily explained by ignoring the fact that light generally includes radiations of different wavelength and by supposing that we are dealing with a scene illuminated in monochromatic light, sodium light, for example. Each part of such a scene is imaged by the lens system of a viewing eye on a particular area of the retina and the illumination of this area is proportional to the brightness of the corresponding part of the external scene. Since light of only one wavelength is involved, the brightness and the retinal illumination can be expressed in purely physical units, as ergs per sec. per unit area, emitted or received. The absorption, in part, of the light falling on each small element of the retina, by photosensitive substances contained in the special retinal receptor cells — the rods and cones — sets going nerve pulses in the nerve cells of the retina, which are finally relayed along the optic nerve to the brain. The complete system of nerve pulses carried by the optic nerve embodies all the information about the external scene which is obtainable through the medium of the eye. Thus the distribution of illumination over the retina determines what we see, and the distribution of brightness in the external scene determines the distribution of illumination over the retina. But, put in this way, the picture is deceptively simple. In the first place the properties of the layer of receptor cells and their nervous connections back to the brain vary at different parts of the retina, so that equality of retinal illumination does not mean that the visual sensations produced will be the same; coupled with this is the fact that the receptors are not independent units and the visual response in a particular small area of the retina depends in general not only on the illumination of that area but also on the illumination of surrounding areas. Some results bearing on these questions will be discussed below.

The proportionality of retinal illumination to external field brightness is also not so simple as it seems. The proportionality constant is not strictly a constant: it depends on the effective area of the pupil which varies both with the brightness level and brightness distribution in the scene (over a range of about 16 to 1 for young eyes), and with the position in the visual field of the object brightness considered. The embedding of the pupil in the optic media of the eye has the effect of reducing considerably the latter variation (see Fig. 1).

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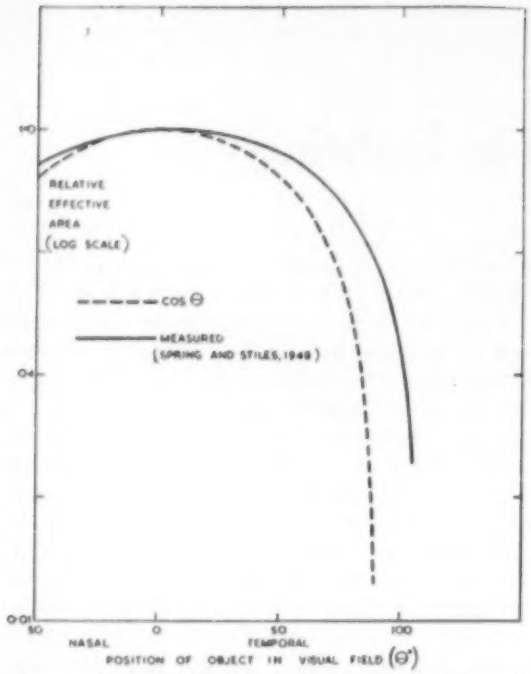



**Figure 1. Relative effective pupil area for objects at different angular separations from the fixation direction.**

If the eye pupil behaved like an artificial pupil outside the eye, its effective area would fall off with the cosine of the angle from the fixation direction: actually the effective area has still about one-fifth its maximum value for an object lying directly to the side of the eye.[1] As people grow older the maximum size to which their eye pupils can dilate in low illuminations is reduced and the lower retinal illumination rather than diminished retinal sensitivity may be mainly responsible for poor vision in these circumstances. But the most important complication is the scattering of light in the eye. Because of this, the illumination of each area of the retina consists of a main contribution of regularly refracted light from the corresponding part of the external field together with smaller contributions of scattered light from the rays proceeding from every other part of the field. The amount of the scattered light is not easy to determine and at the present time the best estimates are those made in 1938 by LeGrand.[2] Using LeGrand's data a calculation of the illumination within and around the retinal image of a light source can be made, and this has been done (a) for the ball of a 100-watt Pointolite lamp of 0.1-inch diameter at a distance of 6 feet, (b) for an 8-inch diameter globe source of the same candlepower (taken as 100) at the same distance (Fig. 2). The retinal illumination is expressed indirectly by specifying the external luminance which would produce it by normal refraction in the eye.

The scattered illumination, although small compared with the illumination in the image, is certainly one cause of the impairment of vision by glare in the neighbourhood of the source. The latter effect has been intensively studied by measurements of the contrast sensitivity *i.e.* of the smallest difference of brightness that the eye can detect, and it has been shown that the presence of the glare source reduces the contrast sensitivity as if a veil of light were interposed between the eye

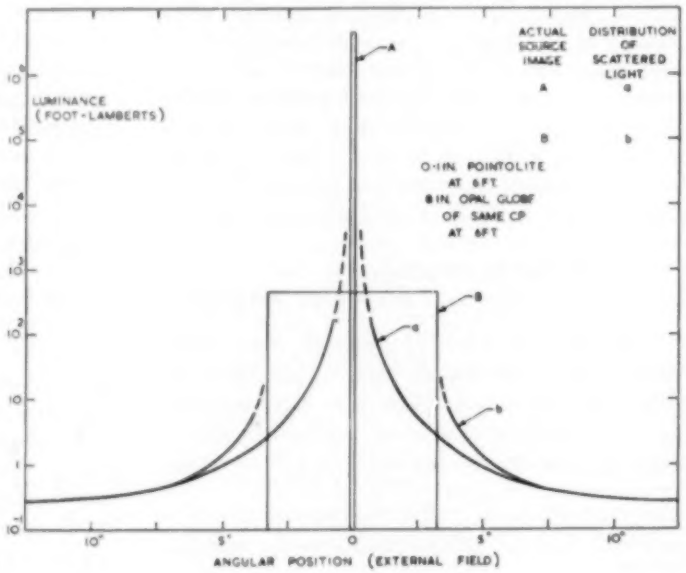



**Figure 2. Illumination in the retinal image of a source and the surrounding distribution of scattered illumination. (Calculated from Le Grand's measurements.)**

and the test object, of a luminance given by the now well-known formula $kB_s\omega/\theta^n$ where $B_s$ and $\omega$ (in steradians) are the luminance and angular area of the source, and $\theta$ is the angular separation of source and test object (in degrees). For the constants $k$ and $n$ the values $k = 10$, $n = 2$, appear to be the best to suit a test area in the direction of vision and an angle $\theta$ in the range 1 to 30 degrees. It does not follow from this work that the equivalent veiling brightness will also reproduce other glare effects. The lowering of the apparent brightness of objects in the neighbourhood of the glare source, the knowledge of which we owe largely to Schouten,[3] would appear at first sight to be an effect which could not be reproduced by means of a veiling brightness, and this instinctive conclusion has certainly influenced Schouten in the interpretation of his work. But, as shown a few months ago by Fry and Alpern,[4] the conclusion is incorrect; a veiling brightness does reduce the apparent brightness of a test object and the luminance of the veil to match the effect of a glare source is not very different, in the range of glare angles studied (0.75° to 4.5°), from that derived from the formula quoted above. The effect of a glare source on the contrast sensitivity for test objects seen by indirect vision right out to the periphery of the visual field,[5] is also represented by the veiling brightness formula, but with a somewhat larger value of the constant $k$, and the recovery of the eye, determined by measurements of the visual threshold, follows the same course after exposure to the glare source or to the equivalent veiling brightness.[6] All these results are consistent with and in fact point to scattered light being the cause of the measured glare effects, but that does not mean that no true interaction between different areas of the retina is taking place. For example, in Fry and Alpern's work, if the veiling brightness were applied only to the test object the apparent brightness of the latter would if anything be increased. It is really the illumination of the retinal areas immediately surrounding the image of the test object which causes the lowering of the apparent brightness and this entails local interaction. On this view glare acts not through a long range interaction of the visual processes occurring at the images of the glare source and test object respectively, but by a purely physical scattering of light supplemented by local interaction effects. If LeGrand's measurements of scattered light are accepted, however, this statement must be qualified. LeGrand[2] determined the scattered brightness and the equivalent veiling brightness for the same subject. He found that the proportion of the equivalent veiling brightness that could be attributed to an actual illumination of scattered light varied from about 92 per cent at a glare angle of 1° to 46 per cent at 30°. This would imply that long range interaction unconnected with the effect of scattered light may become of comparable importance with it, as the distance apart on the retina increases, although of course the magnitude of the total effect is diminishing rapidly at the same time. Application of the method and formula of equivalent brightness to problems of acute glare, notably to the headlight problem, has proved their value to the illuminating engineer. It is just when the glare effect on contrast sensitivity or apparent brightness is very slight that the experimental basis of the formula becomes uncertain — the formula makes no attempt to include several small effects which are known to occur — and, at the same time, the interpretation in terms of scattered light is questionable.

### C.I.E. Brightness (Luminance)

When radiations of different spectral energy distribution have to be considered brightness comes in in another way. In the first decades of the century photometrists and illuminating engineers came to the conclusion that the lighting value of sources of different spectral distributions should be assessed by their power to produce the sensation of brightness. They assumed that if two uniform light sources of different colour are arranged to illuminate, at equal distance, adjacent patches of a white (non-selective) diffusing surface, and if these patches appear to the eye equally bright, then the sources are of equal value for seeing purposes. They also felt that any workable system would have to be one in which the lighting value of an illuminant containing a number of wavelengths $\lambda_1$, $\lambda_2$ etc. having energies $E_1$, $E_2$ etc. respectively should be a simple weighted sum $\Sigma E_n V(\lambda_n)$ where the weighting factors $V(\lambda_n)$ were to be found by determining the energies of monochromatic stimuli of different wavelength which gave the same impression of brightness. Their ideas were carried through and photometric brightness or luminance of a surface emitting per sq. ft. $E_1$ watts of wavelength $\lambda_1$, $E_2$ of wavelength $\lambda_2$ etc. is now defined to be the weighted sum $680\,\Sigma E_n V(\lambda_n)$ footlamberts, the weighting factors (or relative luminous efficiencies ($V_\lambda$) as they are now called) being internationally agreed mean values (C.I.E. 1924) based on several series of measurements made at moderate brightness levels (about two footlamberts) with a small photometric field of 2° diameter, by either the flicker or the step-by-step method of heterochromatic photometry.

At the present time some photometrists are not entirely happy with this procedure of determining luminance (a) because doubt is felt about the correctness of the luminous efficiencies $V_\lambda$ in the blue end of the spectrum and (b) because evidence has accumulated that any coloured patch of high saturation, such as a spectrum colour, placed by the side of a white patch of the same luminance, will appear brighter than the white patch to most observers. Difficulty (a) could be put right by a revision of the factors $V_\lambda$ and several research laboratories are making new measurements to this end. But difficulty (b) is more serious because it implies that brightnesses don't add up. For example, if a patch of red light matches in brightness a patch of white light and a patch of green light matches a second patch of white, then the mixture of the red and green lights will appear less bright than the mixture of the two white lights. The evidence for this anomaly has recently been well summarised by Dresler,[7] and Fig. 3 taken from his paper shows how much brighter highly saturated colours appear than would be expected from their luminances determined on the C.I.E. basis. The magnitude of the effect depends on the precise conditions of observation (the data of Fig. 3 refer to rather low luminance levels, some one to three footlamberts and a 7° matching field) and certainly with the less saturated colours with which the illuminating engineer has mainly to deal, the effects are much smaller. Sodium light is of course highly saturated but it happens that for yellow light the anomaly is of least importance (see Fig. 3). Quite recently, however, two other experimental results have been obtained, one concerning brightnesses in the periphery of the field of view, the other

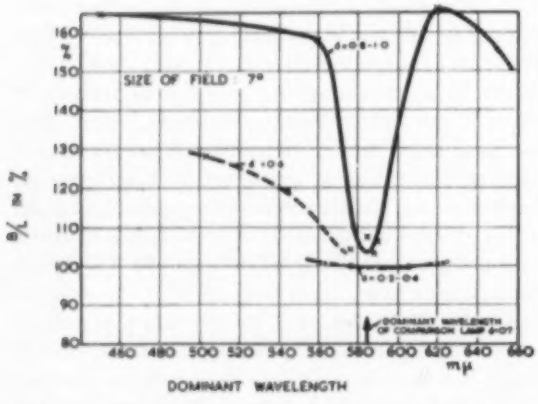



**Figure 3. The ratio $B/L$ of the apparent brightness to the C.I.E. luminance for colours of various dominant wavelengths and high or low saturations. (Means for 9 observers.) (Dresler, 1953.)**

brightnesses of very high value, which I think merit the attention of the illuminating engineer and emphasize the caution necessary in applying C.I.E. brightness (luminance) to conditions widely different from those under which the luminous efficiencies $V_\lambda$ were determined. Brightness is less simple than our method of calculating luminance would suggest and the complications are closely linked with the fact that in the eye we have to deal not with a single mechanism but with several, each having its own spectral sensitivity. Before discussing the new results just mentioned, I want to consider this question of different visual mechanisms which appears to me one of the most important in trying to form a picture or model of what happens in vision.

### Rod and Cone Mechanisms

The distinction between the rod and cone mechanisms of vision is a familiar one. In the central or foveal region of the retina, corresponding to an area of about 2° diameter in the external field, almost all of the photoreceptors are cones so that the C.I.E. factors $V_\lambda$ should represent the spectral sensitivity curve of the cone mechanism. Outside this small central area the retina contains both rods and cones and at very low levels of brightness, the rods are much more sensitive than the cones. Thus under these conditions the brightness of objects seen in indirect vision is determined by the spectral sensitivity curve of the rod or scotopic mechanism for which the C.I.E. two years ago agreed on a modified set of weighting factors $V_\lambda{}^1$ (Fig. 4).[8] The scotopic luminance is then defined in the same way as the photopic luminance, to be $1746\ \Sigma E_\lambda V_\lambda{}^1$ (Scotopic footlamberts if $E_\lambda$ is expressed in watts emitted per square foot). Actually the scotopic or rod factors $V_\lambda{}^1$ are easier to determine than the photopic or cone factors $V_\lambda$ because the rod mechanism gives the same white or greenish or bluish sensation whatever the wavelength of the light. The displacement of the spectral sensitivity curve of the rod mechanism, with respect to the cone curve, towards shorter wavelengths, causes the darkening of red compared with blue objects when the illumination is reduced to very low values — the well-known Purkinje effect.

How do these two visual mechanisms work together as the brightness is raised above the low level — corresponding to a white luminance or less than $3 \times 10^{-4}$ footlamberts — at which light of all wavelengths is seen by means of the rods alone? One interesting approach to the question is to consider the visibility of a brightness contrast between objects of different brightness and perhaps of different colour seen in slightly indirect vision so that

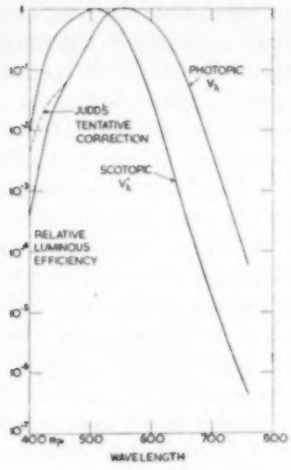



**Figure 4. (left) Present C.I.E. relative luminous efficiencies $V_\lambda$ and $V_\lambda{}^1$ for photopic (cone) and scotopic (rod) vision respectively.**

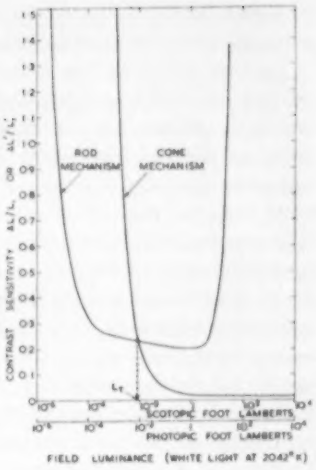



**Figure 5. (right) Contrast sensitivities, $\Delta L^1/L_1{}^1$ and $\Delta L/L_1$ respectively, of rod and cone mechanisms for different levels of white light (colour temperature 2042°K).**

both the rod and cone mechanisms are involved. The photopic or cone luminances on the two sides of the dividing line, $L_1$ and $L_2$ say, can be calculated from the $V_\lambda$ factors and the two scotopic or rod luminances $L_1{}^1$ and $L_2{}^1$ from the $V_\lambda{}^1$ factors. If the cone mechanism were acting alone an approximate measure of the visibility of the contrast (at least for not too high contrasts) would be obtained by taking the ratio of the difference $(L_2 - L_1)$ to the smallest difference $\Delta L$ that can be detected by means of the cone mechanism. Similarly the ratio $(L_2{}^1 - L_1{}^1)/\Delta L^1$ is a rough measure of the visibility for the rod mechanism acting alone, $\Delta L^1$ being the smallest difference of scotopic luminance detectable by the rods. The visibility of the contrast when both mechanisms are in operation will be mainly determined by the greater of the ratios $(L_2 - L_1)/\Delta L$ and $(L_2{}^1 - L_1{}^1)/\Delta L^1$. The smallest perceptible differences $\Delta L$ and $\Delta L^1$ will of course depend on the actual luminance levels, specified say by the means $\dfrac{L_1 + L_2}{2}$ and $\dfrac{L_1{}^1 + L_2{}^1}{2}$ or by the lower luminances $L_1$ and $L_1{}^1$, for the cone and rod mechanisms respectively.

The connection between the smallest perceptible difference and the brightness level, for different visual mechanisms has been much studied in recent years by a method (the two-colour threshold method)[9] which turns to account their different spectral sensitivities. For example by working with a field of red light which has a much greater effect on the cone than on the rod mechanism ($L_1$ the photopic luminance of the field, much greater than $L_1{}^1$ the scotopic luminance) and by producing a contrast by adding to the field a test stimulus of green light which stimulates rods more than cones ($L_2{}^1 - L_1{}^1$ greater than $L_2 - L_1$) we can ensure that the contrast is seen by the rod mechanism up to relatively high levels. In the latest work by this method[10] the increase of the smallest contrast perceptible by the rod mechanism, $\Delta L^1$, with $L_1{}^1$, has been determined up to a level of about 30 scotopic footlamberts (corresponding, for white light (2042°K) to the same number of ordinary or photopic footlamberts), and the rod curve of Fig. 5 shows the mean values of $\Delta L^1/L_1{}^1$ for four observers. A particularly large test object (9° diam.), centered 9° from the fixation direction, was used as one means of retaining rod vision of the test object up to the highest level possible. No corresponding data for cone vision of a test object of this size and position are available but sufficient work on indirect (extrafoveal) vision has been done to show that the variation of $\Delta L/L_1$ with $L_1$ is similar to the cone curve of Fig. 5 which refers to pure cone vision of a 1° test object viewed directly (foveally). A diagram similar to Fig. 5 provides the basis for discussing the visibility of pure brightness contrasts in white light, a pure brightness contrast being one between similar spectral distributions so that $(L_2 - L_1)/L_1 = (L_2{}^1 - L_1{}^1)/L_1{}^1 = C$ say. The rod and cone visibilities are then $(L_2{}^1 - L_1{}^1)/\Delta L^1 = C/(\Delta L^1/L^1)$ and $C/(\Delta L/L)$ respectively. The curves intersect at a transition luminance $L_T$* and at lower luminances $\Delta L^1/L_1{}^1$ is less than $\Delta L/L_1$ so that contrasts will be seen predominantly by rod vision. At higher luminances $\Delta L/L$ is less than $\Delta L^1/L_1{}^1$ and the reverse, is true. For pure brightness contrasts in light of some other colour, the photopic and scotopic scales and with them the cone and rod curves of Fig. 5 are displaced with respect

*In Fig. 5, $L_T$ is about 0.008 footlamberts, but the particular value cannot be insisted on as the rod and cone curves don't refer to identical test conditions.

to each other but the photopic luminance of the point of intersection is not much changed.

The new point in Fig. 5 is the sharp upturn in the rod curve of Fig. 5, beginning at about 2.5 footlamberts. Above this luminance the contrast sensitivity of the rod mechanism deteriorates and it is estimated that for luminances above 200 footlamberts even the highest contrasts would be invisible to the rods which, in effect, become saturated. The situation seems to be that in the luminance range $L_T$ (0.008) to 2.5 footlamberts although weak contrasts are visible only by cone vision, for higher contrasts rod vision may still play some part. But above 2.5 footlamberts any such contribution of the rods is diminishing rapidly. The approach to saturation of the rod mechanism has been studied only for 5° and 10° indirect vision and it remains to be demonstrated that the same thing happens in more peripheral vision.

It is tempting to speculate whether the saturation of the rod mechanism may not have some connection with discomfort glare. Petherbridge and Hopkinson[12] consider that below a certain source brightness discomfort is not experienced however low the surround brightness: for the largest glare source ($2.7 \times 10^{-2}$ steradians) studied by them the lower limit appears to lie between 10 and 50 footlamberts, a range in which, for 10° indirect vision at least, the rods are nearing saturation. But if rod saturation were a major factor in discomfort glare it is difficult to see why increasing the surround brightness and reducing the source size should make much higher source brightnesses acceptable.

The simple idea of scotopic and photopic visibility of contrasts can also be applied when the contrasting luminances have different spectral compositions. For example, given the scotopic and photopic luminous efficiency factors $V_\lambda$ and $V_\lambda{}^1$ and a diagram of contrast sensitivities similar to Fig. 5, it is possible to find by calculation the energies of a series of monochromatic patches, of wavelengths stepping from the blue to the red of the spectrum, each of which has minimal contrast with its neighbours and which, therefore, on the present view is in brightness match with them. These energies can be determined starting with any given energy at one fixed wavelength. The reciprocals of the energies plotted against wavelength represent a kind of relative luminous efficiency curve and by taking in turn a series of increasing energies at the fixed wavelength, the changes in the curve in passing through the region of mixed rod and cone vision can be followed. An early calculation on these lines is compared in Fig. 6[13] with direct measurements by Walters & Wright[14] of the relative luminous efficiency for slightly indirect vision in the transition region. The main changes on raising the level —an initial rise in the red followed by an apparent shift of the curve towards longer wavelengths—are approximately reproduced by the derived curves. It appears in fact that there is an intimate connection between the contrast sensitivities of two mechanisms of different spectral sensitivities and the way the mechanisms operate together to produce the sensation of brightness.

### Different Mechanisms of Cone Vision

Cone vision is not of course served by a single visual mechanism, although fortunately it is possible to go some way on that assumption, as has been done here, without serious error. The laws of colour mixing make it probable that in cone vision at some stage there are three processes involved, to each of which corresponds a different spectral sensitivity. By applying the two-colour threshold method already mentioned to the study of the perception of contrast by cone vision it has been found possible to distinguish different mechanisms of

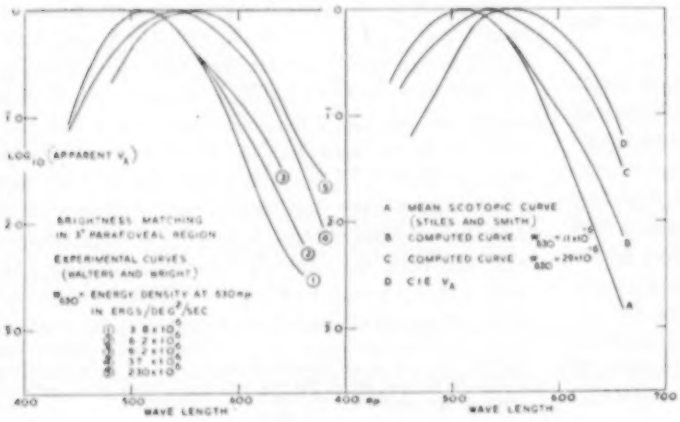



**Figure 6. Comparison of the $V_\lambda$ curves for intermediate brightness levels as measured by Walters and Wright (1943) and as derived by the method based on contrast sensitivities (Stiles, 1944).**

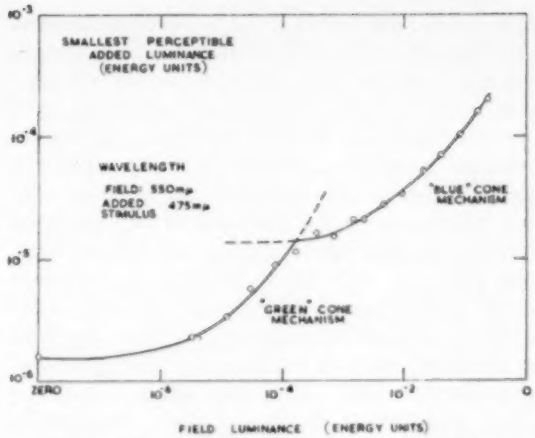



**Figure 7. Variation of the smallest perceptible additional luminance of a 1° test stimulus of wavelength 475 mμ with the luminance of the monochromatic background field of wavelength 550 mμ to which the test stimulus is added. Both luminances expressed in energy units. Direct (foveal) vision.**

cone vision in the same way as the rod mechanism is distinguished from the cone mechanism. The easiest separation to establish is one between a mechanism with maximum sensitivity in the blue at about 445 mμ and another with maximum sensitivity in the green at about 540 mμ. If, for example, the eye views a moderate-sized field (say 10° diameter) lighted in monochromatic green light (550 mμ) in turn to a series of luminances from zero upwards, and a contrast is produced by adding to the field at its centre a small 1° diameter test stimulus of monochromatic blue light (475 mμ) the smallest perceptible intensity of the added blue light varies with the field luminance in the way shown in Fig. 7. The clearly marked separation of the curve into low and high intensity branches recalls the kind of data often used to show the transition from rod to cone vision. But here it seems certain that rod vision is playing no part. The test stimulus, viewed by direct vision, is small enough for its image to fall well within the rod free area of the retina and subsidiary tests on adaptation times and directional sensitivities confirm that the contrast is being seen by cone vision only. It may also be noted that the transition occurs at a luminance of about 4 footlamberts, which greatly exceeds the luminances associated with the transition from rod to cone vision. The two branches of the curve of Fig. 7 are attributed to two distinct mechanisms of cone vision, one of which takes over the perception of the test stimulus, from the other at the transition luminance, the two broken-line extensions of the branches indicating the curve that would be obtained if one or other of the mechanisms were absent or failed to act. When the wavelengths of the test stimulus and field luminance are changed, the curve is modified in a way corresponding to independent shifts of the component branches parallel to the axes, and by determining these shifts the spectral sensitivities of the mechanisms responsible for the branches can be found.

It was first thought[15] that the results of measurements by this method could all be explained in terms of just three cone mechanisms which would correspond to the three processes underlying the trichromatic theory of colour matching. Later work indicates that more than three cone mechanisms must be assumed although what are probably the three main mechanisms have spectral sensitivities which suffice nearly but not quite, to explain the experimental results of colour-matching.[11] These spectral sensitivities are shown in Fig. 8. An interesting difference between the mechanisms is that while at moderately high luminances the contrast sensitivities of the "red" ($\pi_5$) and the "green" ($\pi_4$) mechanisms are nearly equal the "blue" ($\pi_1$) mechanism is only about one-fourth to one-fifth as sensitive. This has the effect that in the relative luminous efficiency curve for cone vision derived from the properties of the individual cone mechanisms by the method already discussed for the rod and cone case, the influence of the "blue" mechanism appears only as a hump at short wavelengths. A comparison of the curve derived in this way (but

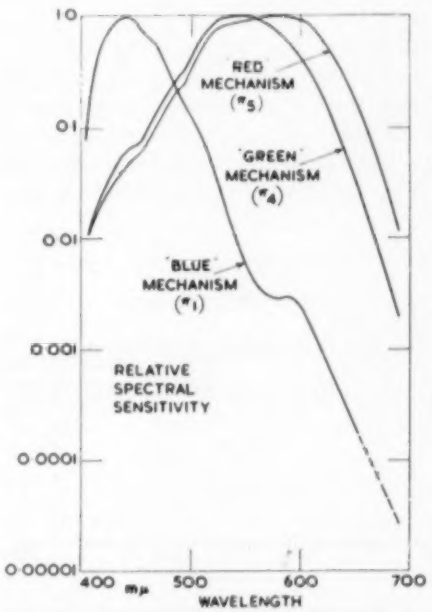



**Figure 8. Relative spectral sensitivities of three main mechanisms of cone vision (Stiles, 1953).**

based on some earlier determinations of the spectral sensitivities of the mechanisms), with the C.I.E. $V_\lambda$ curve shows fairly good agreement except at short wavelengths where it may well be the C.I.E. curve is in error (Fig. 9).[13] This derivation will have to be reconsidered when enough is learned about the additional foveal cone mechanisms brought to light in recent work, although it is unlikely that the resulting curve will be much changed.

### Brightness in the Peripheral Field

Of more concern are the properties of the cone mechanisms outside the small central region of the retina and the dependence of brightness on colour in the outlying parts of the visual field. An obstacle in investigating these questions is the presence of the rod mechanism. However, by making the level of adaptation sufficiently high the response of the rod mechanism can be kept out of the picture, and the results then obtained indicate that the region of the retina immediately surrounding the fovea contains cone mechanisms generally similar to those in the rod-free area. Until recently the observations had not been extended beyond 5° from the fixation direction, but in the last two years Weale[16] has made measurements of relative luminous efficiency out to 70°. He kept the adaptation level high by viewing the two small fields whose brightness had to be matched through holes in a screen illuminated to 1.5 or 100 footlamberts of white light. The comparison field of wavelength 564 mμ was set at approximately the same brightness as the surround and the monochromatic field was then matched with it. According to the remarkable results he obtained for the $V_\lambda$ factors in light adapted peripheral vision (Fig. 10), the relative brightness in the blue end of the spectrum increases dramatically in moving out from the fixation direction. For the high luminance surround at the peripheral angles 25°, 45°, 70°, the wavelength of greatest luminous efficiency is in the blue at about 450 mμ, and the shapes of the curves suggest that the "blue" mechanism, which contributes little to brightness for foveal vision, becomes increasingly important in the periphery and probably has the highest contrast sensitivity.

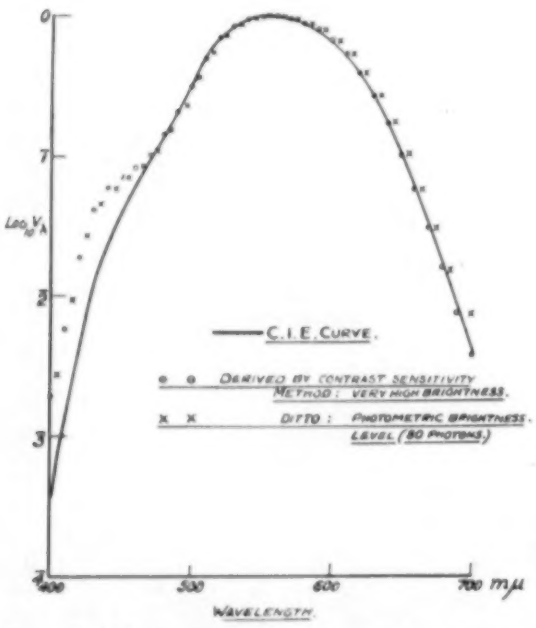



**Figure 9. Relative luminous efficiency curves for cone vision derived by the method based on contrast sensitivities compared with the C.I.E. $V_\lambda$ curve.**

If further work bears out these results of Weale it appears that in going from central to peripheral vision the illuminating engineer will have to deal with something very much like the Purkinje effect. As with the latter, the difficulties only arise when the relative luminances for different spectral distributions are in question. On the basis of Weale's factors for 25° eccentric vision I have made an approximate calculation of the relative brightnesses of various practical spectral distributions, all of the same C.I.E. luminance, supposed viewed under conditions of high light adaptation (white). Whether these differences are likely to be of practical import is not yet clear. An outstanding question in Weale's experiments is whether the colour of the light adaptation (nominally white) may not be a complicating factor.

### Brightness at Very High Intensity

The second new result on brightness and colour which I referred to earlier is due to Ferguson,

**TABLE I.—Relative brightnesses for different spectral energy distributions, evaluated using Weale's determinations of relative luminous efficiency for 25° eccentric vision by the light-adapted eye. The C.I.E. luminance is assumed to be the same for all the distributions.**

| Spectral distribution of radiation | Relative brightness on Weale's relative luminous efficiency curve |
|---|---|
| Tungsten lamp at C. T. 2042°K | 1.0 |
| Tungsten lamp at C. T. 2854°K | 1.26 |
| Daylight (C. T. 6500°K) | 2.31 |
| Blue sky (C. T. 20,000°K) | 3.35 |
| Medium pressure Mercury Lamp | 1.37 |
| Very high pressure compact source mercury lamp | 2.60 |
| Sodium lamp | 0.43 |
| Fluorescent lamp Daylight ("Northlight") | 2.05 |
| Fluorescent lamp (Mellow) | 1.28 |
| Light from the walls of a room decorated in pink with | |
| (a) daylight fluorescent source | 1.27 |
| (b) mellow fluorescent source | 0.89 |

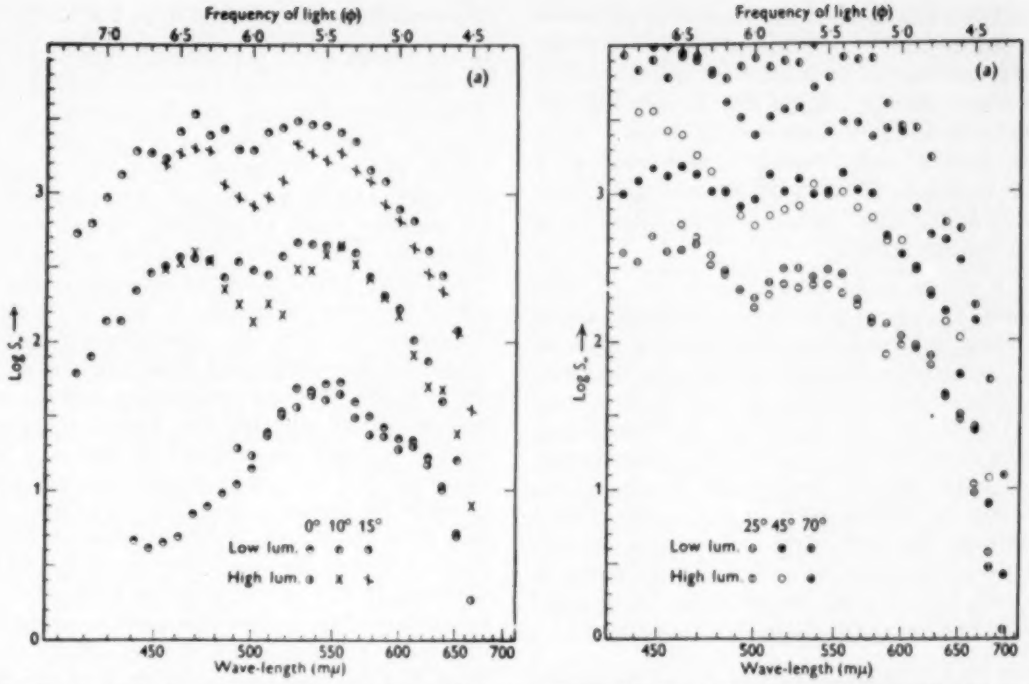



**Figure 10. (a, left; B, right) Relative luminous efficiencies determined for vision at different angular separations from the fixation direction, with the eye adapted to moderate (1.6 footlamberts) and high (100 footlamberts) luminances of white light (Weale, 1953).**

Reeves & Stevens,[17] who were prompted to compare the glare from mercury and sodium lamps by what appears to be a significant preference for sodium street lighting expressed by many people. They set up at a separation of 15.5 inches two rectangular sources (4" x 8.5"), one emitting sodium light of luminance 44 cd/in$^2$, the other emitting H.P. mercury light of a luminance which could be varied, the background being dark. The observer at a distance of 80 feet was asked to look at the sources and say which, if any, was more "glaring," on first looking and after one minute. Using a group of at least 12 observers and scoring their replies in a suitable way, these workers found that for equal luminance nearly all observers judged the mercury more glaring and its luminance (C.I.E.) had to be reduced to about one-third of that of the sodium for opinions to be equally divided (Fig. 11). Similar tests with a tungsten source placed the latter between mercury and sodium, and other observations showed that background brightnesses up to one footlambert reduced the difference between the sources but only slightly, a background of 10 footlamberts having no further

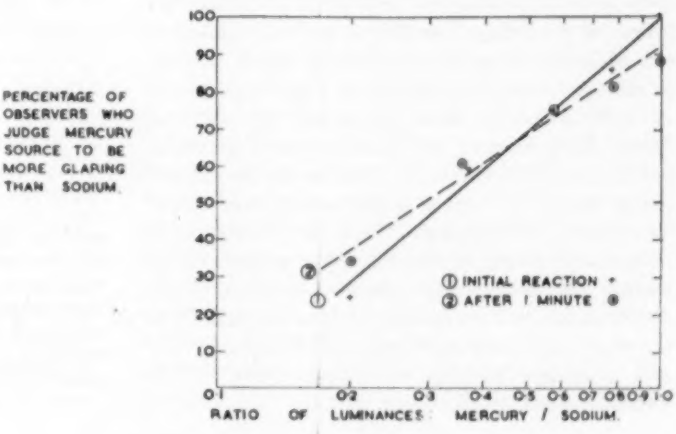



**Figure 11. Analysis of observers' judgments of the glaring effects of mercury and sodium sources of identical dimensions for various values of the ratio: luminance mercury/luminance sodium, the sodium luminance being fixed at 44 cd/in$^2$ (approx. 20,000 footlamberts) (Ferguson, Reeves and Stevens, 1953).**

effect. The arrangement of the experiment leaves little doubt that what subjects were really comparing was apparent brightness, and Ferguson, Reeves and Stevens suggest that at very high intensities the C.I.E. $V_\lambda$ may cease to be valid. They made further studies which showed that at a C.I.E. luminance of 1.5 cd/in$^2$ mercury and sodium sources of the same luminance were judged to be about equally glaring.

It is going to be interesting to see if these changes of apparent brightness at very high intensities can be brought into line with the ideas on cone mechanisms discussed earlier. On the practical side it would be a pity to draw hasty conclusions about the relative merits of mercury and sodium street lighting. A great many other factors enter and it may be recalled that in a model experiment employing light sources of the correct brightness, Dunbar[18] could not establish any difference in the revealing power of installations in mercury, tungsten and sodium light, for identical distributions of C.I.E. luminance in the street.

### Colour-Adaptation and Colour-Rendering

The starting point in any problem involving colour as colour and not as a disturbing factor in the determination of brightness must be the experimental laws of colour-matching. According to these, two luminances of different spectral distributions will match completely *i.e.* in brightness and colour, if three weighted sums $\Sigma E_\lambda x_\lambda$, $\Sigma E_\lambda y_\lambda$, $\Sigma E_\lambda z_\lambda$, (the so-called tristimulus values) have respectively the same values in the two cases. Again the internationally agreed weighting factors or distribution coefficients $x_\lambda$, $y_\lambda$, $z_\lambda$ are based on colour-matching experiments made in the small central area of the visual field, $y_\lambda$ being identical with the relative luminous efficiency $V_\lambda$. A more far-reaching limitation is that while the colour-matching data show when different spectral distributions produce the *same* colour, they provide no means of predicting how this colour will appear to the observer when the modifying effects of surroundings of different hue or of prior exposure to variously coloured fields are taken into account. These effects have of course always been occurring but it is mainly colour troubles in the use of discharge lamps of various kinds, which have stimulated their investigation. When the illuminant is changed the colour of any particular object will be altered for two distinct reasons. Because of the different spectral composition of the incident light the object will have a different C.I.E. chromaticity $x$ $y$ $z$ as specified by the rated values of the weighted sums

$$x = \Sigma E_\lambda x_\lambda / [\Sigma E_\lambda x_\lambda + \Sigma E_\lambda y_\lambda + \Sigma E_\lambda z_\lambda].$$

In the second place, the chromaticities of all the surrounding objects and surface will have their chromaticities changed, and by a purely visual effect the apparent colour of the original object will be modified. These two effects tend to oppose each other and the net changes of apparent colour are less than might be expected. In the study of the purely visual effect — the colour-adaptation — Wright's method of binocular colour-matching has proved the most successful. In Hunt's[19,20] use of the method the left eye of an observer views a colour stimulus surrounded by an extended adapting field, and the right eye views an entirely independent colour stimulus and adapting surround field. The fields are arranged so that with both eyes open the two colour stimuli are seen juxtaposed in the binocular field, and by using a variable three-colour mixture for one stimulus the apparent colour of the other stimulus can be matched with any desired pair of adapting fields. The surround field of the three-colour mixture can be kept at a fairly high luminance of a particular "white" light, and the matching proportions of the three colours then define on a common reference system the apparent colour of the stimulus seen under different surround conditions by the other eye. Hunt found that for both large (20°) and small (1°) colour stimuli of fairly high C.I.E. saturation and for all dominant hues, the apparent colour was less saturated the lower the level of light adaptation as determined by the white light surround. The loss

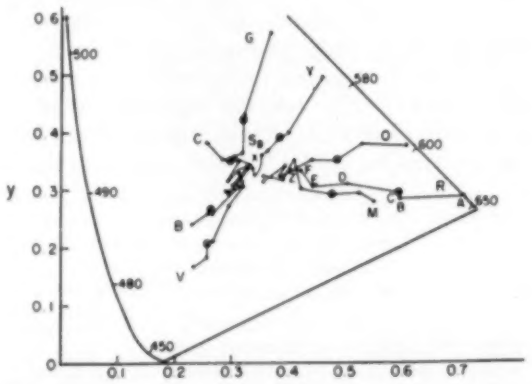


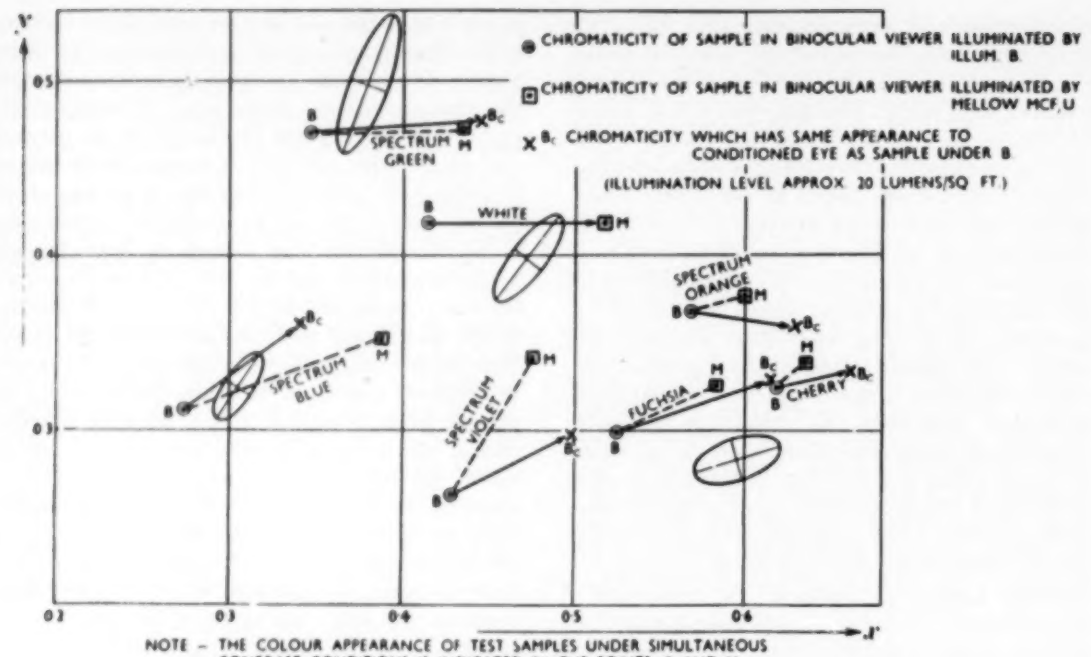

**Figure 12. Change in apparent colour of eight stimuli (*R, O, Y, G, C, B, V, M*) of fixed C.I.E. chromaticity (corresponding approximately to the ringed point on each line) as the equal test and surround luminances were decreased together in steps from *A* (300 footlamberts approx.) to *F* (0.02 footlamberts approx.). An additional observation with zero surround and test luminance of approx. 0.02 footlamberts is also included (Point *Z*). For the chromaticity *R*, the points for the different levels are labelled: *A, B, C, D, E, F, Z*. (Hunt, 1953).**

of saturation is by no means small (Fig. 12). This finding has both theoretical and practical consequences. Since about the same desaturation was observed with the 1° stimulus, which falls within the rod-free area of the retina, and the 20° stimulus, it seems that the intrusion of a white sensation produced by the rods cannot be the cause. Again, the fact that all hues are desaturated implies that a mere shift in the relative overall sensitivities of just three non-interacting colour mechanisms as the adaptation level drops, cannot provide an explanation for on that view some colours would become more saturated. One of the hypotheses considered by Hunt is that there is a special white mechanism, additional to three specific colour mechanisms, which contributes white to the colour sensation at low levels but has a diminishing effect as the level is raised. The idea of a special white mechanism has some independent support but as yet it is hardly sufficiently definite to be of value in handling adaptation problems. The conception of three distinct colour mechanisms works better when applied to the variations of apparent colour of objects following a change in the precise chromaticity of the surround brightness. For example, with tungsten light surrounds the apparent colours of objects are all shifted towards the blue in the colour diagram, as compared with their placings for a daylight surround. This is qualitatively consistent with a depression of the overall sensitivity of the "blue" mechanism relative to the "red" and "green" mechanisms when the bluer daylight surround is used.

On the practical side these investigations put a figure to the increasing vividness of colours as the illumination is raised, and they also indicate to what extent colour adaptation will "correct" the changes of chromaticity of objects following a change in the illuminant. More direct evidence on this last point is provided in a series of investigations by Winch and Young[21] who also used a variant of the binocular matching method and determined (a) the change in chromaticity of a standard series of colour samples (fairly highly saturated) when the illuminant was changed and (b) the change in apparent colour of the samples consequent on the change in colour of the surrounding material following the same change in illuminant. The circle and square points in Fig. 13, taken from their work, represent respectively the chromaticities under daylight (as reproduced by colorimetric illuminant B) and mellow fluorescent lamp light (MCF/U). The line from the circle point to the cross point represents the shift in apparent colour by changing the surround colour from daylight to mellow fluorescent. In this case the surrounds were of white material and had the same chromaticities as the illuminants. If colour-adaptation had completely compensated for the altered chromaticities the cross and square points would have coincided. In the colour-rendering problem it is the separation of the cross and square points which has to be considered, provided, and this is an important proviso, that people may be considered to have been in an installation long enough to have become properly adapted and are not able to see simultaneously rooms lighted by different illuminants. Winch and Young make another important point. The colour of the decoration will produce changes in apparent colour of the same general type as changes in the illuminant. They show for example that if the walls of a room are pink instead of white, the apparent colours of objects alter by amounts similar to those produced by the change from daylight to mellow fluorescent (Fig. 13). It should be noted here that while the source was kept the same, the selective effect of inter-reflections in the rooms was allowed to operate as in practice, and the actual illuminations of the objects had different spectral distributions, as is apparent from the separation of the circle and square points in Fig. 13. The fact remains that rooms illuminated by daylight or tungsten light have been decorated in various colours for a long time without producing the complaints about colour which have followed the introduction of fluorescent tube lighting. It appears that it may not be the actual magnitude of the colour shifts of apparent colour which is the difficulty so much as their direction (in the colour diagram) for familiar objects, and perhaps the distortion of colour relationships in a scene involving several colours.

These last considerations must certainly be given weight in fixing permissible tolerances in the spectrum band method of specifying the colour-rendering properties of light sources. In preliminary work on this problem by my colleague Dr. B. H. Crawford, arrangements were made for the gradual removal of any particular band in the spectrum of an illuminant. The light controlled in this way was allowed to fall on complex test objects such as water colour paintings of scenes. The observer had to say when the removal of a particular band — which was done very slowly so as to allow colour-adaptation to keep pace — had produced a noticeable colour distortion. A pilot experiment showed some promise but one difficulty was insufficient light. This may be remedied by the out-size monochromator employing liquid prisms (of monochloronaphthalene) now being assembled.

The optimum choice of spectral bands for the specification of the colour-rendering of light



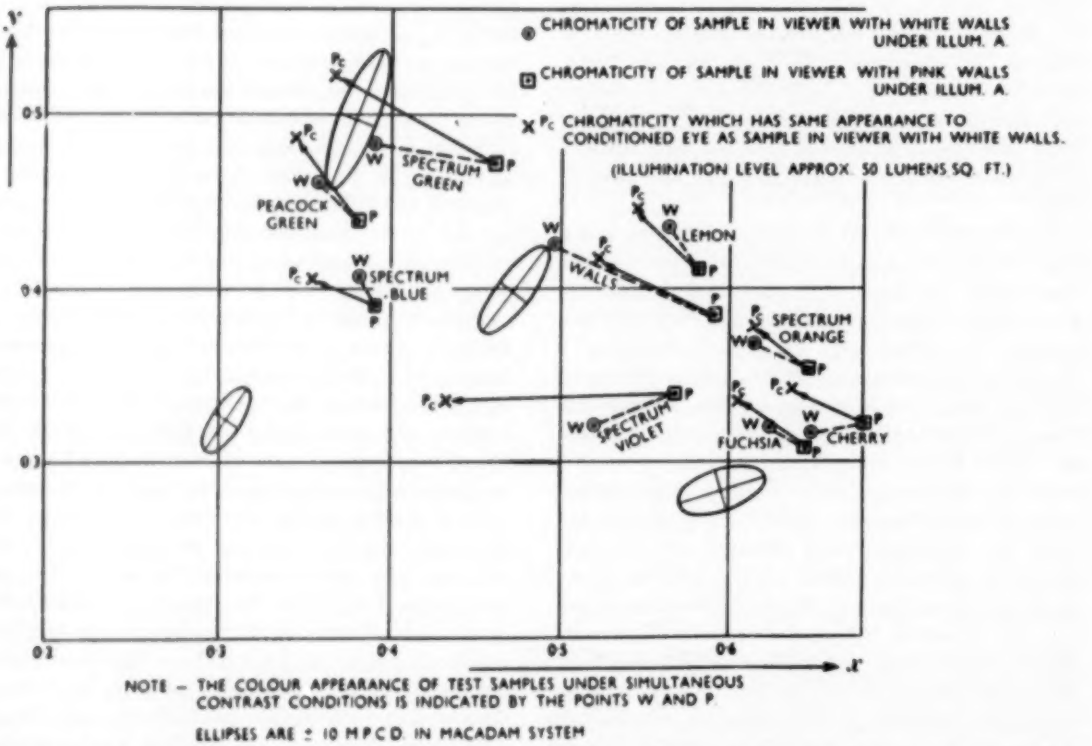




**Figure 13.** (A, top drawing) Change of apparent colour of standard pigment samples with change of conditioning from daylight ($S_B$) to fluorescent "mellow *MCF/U*."

(B, lower drawing) Change of apparent colour of standard pigment samples when the illuminant was kept the same (illuminant A: tungsten lamp at 2854°K) but the walls of the enclosure in which the sample was exposed were changed from white to pink (Winch and Young, 1953).

sources involves factors other than purely visual ones — for example, the types of spectral reflectance curves of the "materials" of everyday life and their frequencies of occurrence — and is in fact a complicated problem. Henderson and Waigh[22] have made recently trenchant criticisms of nearly all that has been done on this problem up to now. They have proposed a simpler criterion of colour-rendering — the red-rendering index, defined as the ratio of the energies (or luminances) at two wavelengths, 650 mμ and 560 mμ divided by the corresponding ratio for a full radiator having the same C.I.E. chromaticity value as the given source. Their object is the relatively modest one of distinguishing between fluorescent lamps which have pretensions to high fidelity colour-rendering and those for which high luminous efficiency is the prime objective. They suggest a red-rendering index of 0.5 as the dividing line between these two types.

### Formulae for Discomfort Glare

A main preoccupation of illuminating engineers in the last few years has been the quantitative connection between the brightness of a source ($B_s$), its angular size ($\omega$) and position ($\theta$) and the brightness of the surround ($B$) when an observer judges the glare from the source to be producing a specified degree of discomfort — just intolerable, boundary between perceptible and imperceptible, etc. Little is known about the physiological or psychological mechanism of discomfort glare. It can certainly be observed in conditions where the eyes' ability to discriminate detail or contrasts is hardly disturbed to a measurable extent. Work by the "appraisal method" has shown that the degree of discomfort glare $G$ can be specified by a formula of the form $G = B_s^m \omega^n / B$, the angular position of the glare source having comparatively little effect in the range of $\theta$ ($\theta$ below 50°) of most practical interest. The formula indicates the sets of values of $B_s$, $B$ and $\omega$ which will produce the same discomfort glare, and in use must be supplemented by a decision on the value of $G$ which would represent an acceptable degree of glare. Different workers have obtained different values for the indices $m$ and $n$ depending on the particular experimental conditions used. American investigators (Holladay, Harrison, Luckiesh and Guth), have usually considered the sensation when the glare source is abruptly exposed or, by an eye motion, is brought to a new position in the visual field, while European workers (Hopkinson, Petherbridge, Vermeulen, Van de Boer) have concentrated on the discomfort when the observer has become adapted to the glare source in a particular position in the field. For the source and field brightness of chief interest, the results are in fair agreement. In fact, Hopkinson in a recent comparison has concluded that the differences between the formulae of different investigators are less than the significant differences in the glare assessments of different observers, and that for practical purposes they can be ignored. They way seems open for agreement on a standard formula for use by lighting designers, and British workers have suggested that this might be taken to be $G = B_s^2 \omega / B$. Fig. 14, from Hopkinson's paper, shows the relation between source and surround brightness for a source of fixed size giving a constant degree of discomfort, (a) according to the results of individual investigations, (b) according to the proposed standard formula.

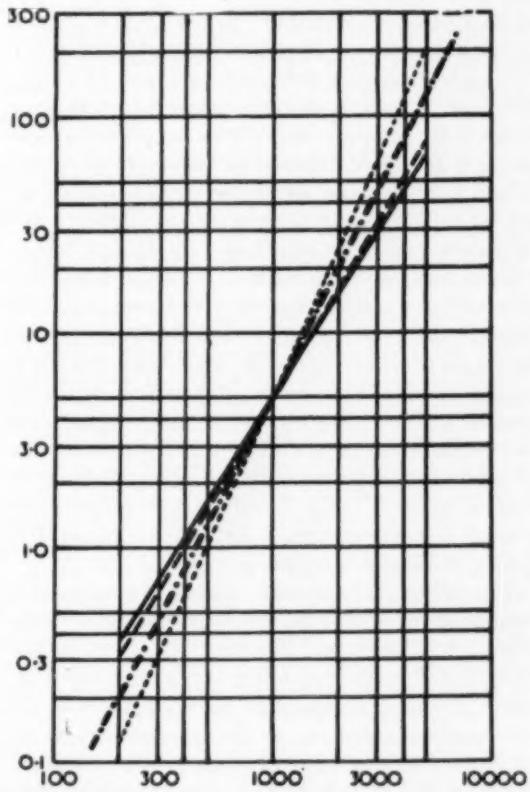



**Figure 14. Relation between surround luminance (plotted as ordinate) and source luminance (plotted as abscissa) to produce a certain degree of discomfort glare, according to different formulae.**

**Vermeulen and de Boer (1948)** — — — — — — — — —
**Luckiesh and Guth (1949)** . . . . . .
**Petherbridge and Hopkinson (1950)** ———————
**Proposed mean:** $\frac{B_s^{1.6}\omega^{1.6}}{B}$ —·—·—·—·—·—·—
**(Hopkinson, 1952)**

### Further Requirements in Lighting

As mentioned in the introduction, there is now a striving for something more in interior lighting than adequate light for the task and freedom from discomfort glare. In a Report "The design of the visual field" — which is just about to appear in the Transactions of the I.E.S. of London, a British comittee* has tried, among other things, to sort out these more subtle elements making for completely satisfactory lighting. One such element is the "phototropic" property of a suitably arranged pattern of brightness and colour which can as it were draw the eye of the beholder to the areas where his interest should lie ("centres of attraction"). Others are the exploitation of sparkle and gloss, and light modelling by which the solidity of objects is accentuated and impressions of depth and spaciousness are enhanced. The characteristics which a pattern should have to provide a centre of attraction have been illustrated by the Dutch architect Kalft in special demonstrations and by examples from the works of great painters. These tend to show, for example, that phototropism towards a centre is greater if the colours change from colder (bluer hues) outside to warmer (redder hues) at the centre. In a comparison of two lighting arrangements made by Hopkinson, an extended uniform source was replaced by one having the same area and average luminance — and producing no greater discomfort glare — but consisting of an aggregate of small patches of high luminance on a dark ground. This source produced an effect of sparkle which observers agreed gave livelier and more satisfying lighting. The dull, flat appearance of solid objects placed inside a photometric integrating sphere (with a suitably screened light source) illustrates what is lost when light modelling is eliminated completely.

The effects just discussed belong to a very wide conception of vision to which psychologists have given much attention. The emphasis is not on the visibility of individual brightness and colour contrasts but on the perception of whole objects, not necessarily simple ones, on the organisation of the field into meaningful or pleasing patterns, and on the contribution of what is seen to the individual's overall feeling of in-tune-ness with his environment. How far is it necessary or useful for the illuminating engineer to pursue these rather abstract notions? Perhaps only to the extent of seeing what are the appropriate measurable quantities he can place as the disposal of architects and interior decorators to help them in their design problems. For example, in modelling, the rate of change of the illumination at a point with the orientation of the surface on which the illumination is measured, appears to be a key quantity whose significance in 3-D accentuation is now being actively studied.

*N.I.C. Committee on Lighting Principles: J. M. Waldram (Chairman), E. S. Brazington, P. V. Burnett, I. G. Holmes, R. G. Hopkinson, M. W. Pierce, A. Pott, W. Robinson, W. S. Stiles, H. C. Weston.

### Visual Performance and Surround Brightness

It may be not inappropriate to end with a more concrete problem: the dependence of visual acuity on test field and surround luminances. Lythgoe's very good data have provided the basis for most discussions of this question up to now but their consolidation and extension are overdue. A careful study for a wide range of cases has just been completed by Mr. W. R. Stevens of the British General Electric Company and he has kindly allowed me to say something of his results in this lecture, before their publication. The visual acuity was measured with the Landolt *C* in a test field of diameter 0.5° and surrounds of outer diameter 0.5° (*i.e.* no surround beyond the test field) to 120°. The results (means for 4 subjects) show very clearly that at not too low test field luminances (above one footlambert), acuity has a well defined maximum at a particular surround luminance which is equal to the test field luminance, or at high values of the latter (about 100 footlamberts or more) is somewhat lower (about one-fifth, when the test field luminance equals 1000 footlamberts). Provided the surround is not very small its actual size is a minor factor. A further point from Stevens' excellent investigation is that with a test field and a large surround of the same luminance, acuity is maximal at about 600 footlamberts but with small surrounds the maximum is shifted to a rather higher luminance of 2 to 3 times the value quoted.

Where Stevens' measurements overlap Lythgoe's they confirm the general trend of the latter although there are some differences. I have said sufficient I think to show that we have here a new set of data which is likely to provide for some years to come the quantitative basis for discussions of a large group of "surround" problems.

### Conclusion

I have ranged rather widely over visual phenomena which have a direct bearing on lighting or which may help to build up a picture of the visual process, useful to the illuminating engineer. The treatment of each topic has been sketchy but will I hope provide a starting point for the discussions of the conference.

In preparing this lecture I have been greatly

helped by conversations about their work with Mr. J. B. Collins, Dr. B. H. Crawford, Dr. R. G. Hopkinson, Mr. W. R. Stevens, Mr. J. M. Waldram, Mr. R. A. Weale and Mr. G. T. Winch. It is a pleasure to express my thanks for this help and also for permission to reproduce Figure 3 (Dr. Dresler), Figure 10 (Mr. Weale), Figure 11 (Mr. Stevens), Figure 12 (Mr. Hunt), Figure 13 (Mr. Winch) and Figure 14 (Dr. Hopkinson).

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## DISCUSSION

S. K. Guth*: At the opening session of the 1953 Technical Conference, Mr. Walter Sammis mentioned briefly the high quality and especially glare-free lighting of today. All of us wish this were true — that we really had, universally, glare-free lighting. We have made great strides in this direction during the past several years, but still have a long way to go. The papers and discussions at this "Light and Vision" technical session illustrate that much thought is being given to brightness and its effects upon human beings by many of our contemporary investigators. This is not a new activity. A quick review of the literature will show that comfort, visual fatigue, ease of seeing and other similar effects have been investigated and discussed almost endlessly.

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It should be of interest to review briefly some of the progress we have made over the years in developing the concept of brightness and comfort. Fundamentally, our philosophy has not changed. Our basic objectives are to apply light and lighting for efficient, safe and comfortable seeing. However, our knowledge and the art and science of illuminating engineering have developed greatly. As they continue to expand in the future, the better we will be able to attain our objectives.

Of the many fundamental factors which influence seeing, brightness is of overwhelming importance. The brightness relationships within the task itself determine directly our ability to see. The brightness relationships in the surrounding area and between the task and surround influence ability to see, but more important, determine the comfort of the entire environment. Therefore, in any discussion of brightness and comfort we are concerned primarily with the brightnesses outside of the task area and their relationship to the task brightness. This does not mean that other factors such as color, texture, pattern, etc. are not important. Each has its place and these last named can be considered as part of the aesthetic aspects of the problem which are, in this discussion, excluded.

Many recommendations and guides for providing visual comfort have been formulated and proposed. Some have been relatively arbitrary, reflecting individual opinion and others have been an attempt to set down in words things gained through experience. A few researches were available, but often they were difficult to apply to typical lighting and visual situations.

About ten years ago the newly appointed Committee on Standards of Quality and Quantity for Interior Illumination (S.Q.Q.) undertook a study of the available information on brightness and comfort. They developed a series of recommendations for the lighting practice committees of the I.E.S. That committee recognized the limitations of the available data and stated that some of their conclusions should be considered tentative. Among their recommendations are the familiar "1 to 1" and "3 to 1" brightness ratios. They also applied the brightness ratio concept to luminaires. Much of their report was based upon the earlier work by Holladay in which the brightness and size of a source and the adaptation brightness are related to a numerical comfort-discomfort index.

Almost from the beginning there were pro and con viewpoints of the S.Q.Q. report. Some believed that the brightness ratios were unduly restrictive while others felt that the ratios should be adhered to implicitly. Consequently, there developed various interpretations and extensions of the brightness ratios. These often resulted in confusion as to just what constituted good lighting practice. In spite of this, it can be said that the report did much to make the lighting specialist very much aware of the importance of giving full consideration to the brightness distribution in the entire visual environment. He knew that if he permitted excessive brightnesses or brightness ratios, people would — and usually did — complain.

During the past few years a number of investigators have extensively studied brightness and comfort. Vermeulen and deBoer, Luckiesh and Guth, and Petherbridge and Hopkinson have provided us with considerable new data which are filling some of the gaps in our knowledge. While each group has used somewhat different techniques in their approach to the problem, all were trying to determine the relative weight assigned to each of the factors involved. There seems to be sufficient agreement among their results

to indicate a possibility of ultimately developing a comfort rating method on a fairly sound basis.

In the meantime, Harrison and Meaker have developed a glare factor system for evaluating comfort of lighting installations. It was originally devised to overcome some of the objections to the S.Q.Q. Committee Report No. 1. With later modifications indicated by the newer experimental data, it has been found to agree quite well with experience.

Logan has studied certain outdoor brightness patterns and used them as guide to define and describe desirable flux distribution ratios in the field of view. More recently, Logan and Lange have applied certain of the new experimental data to develop a mathematic procedure for determining the probable comfort of a lighting installation.

In their papers at this session Mr. Weston and Dr. Stiles have covered in some detail many important aspects of visual fatigue and discomfort produced by undesirable brightness relationships. In fact, they have summarized, in part, many of the discussions that have taken place in the S.Q.Q. and lighting practice committees of the I.E.S. So many factors can influence comfort and discomfort that it sometimes seems an endless task to resolve them.

Where does this lead us? It is evident that many individuals have and are giving much thought to the problem of brightness and comfort. The present S.Q.Q. Committee is evaluating all the new data and the various suggested quantitative methods of evaluating comfort. Its objective is to reconcile the various viewpoints and approaches and determine how Report No. 1 should be modified. Then it may be possible to develop a single comfort rating system which can be used as a guide for any lighting situation. Such a system will enable us, as lighting engineers, to come nearer to our goal of providing visual comfort as well as ability to see.

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**Harry Helson**

# Color and Vision

IN EVERYDAY LIFE the multiplicity of stimuli reaching the eyes is very great and is complicated by the fact that the eyes are in constant movement. At first sight this would seem to preclude any valid inferences from laboratory studies involving fairly steady visual states to everyday conditions where stimulation is constantly changing. Fortunately the visual mechanism acts like an averaging device, averaging reflectances or luminances, both as regards their light and color aspects, according to their intensity and distribution in time and space. The eye shifts its zero or adaptation-level to coincide with a weighted log mean of all stimuli im pinging upon it in any viewing situation. This has the effect of reducing the range of visual response from 10 or 50 billion to 1, as measured under extremes of light and dark adaptation, to about 100 to 1 under any given set of conditions. Dr. Stiles[1] points out "Brightness is less simple than our method of calculating luminance would suggest." I believe he must have something like this reduction in range due to adaptation in mind. Nearly 20 years ago Dr. Judd and I began using the concept of lightness in place of brightness to take account of the fact that non-selective papers above 10 times background reflectance are all called white while non-selective papers below one-tenth background reflectance are all called black. Even brightness differences in luminous sources wash out above and below the hundred-fold range around any given adaptation-level. In the case of objects which reflect light, differences in chromaticness also tend to wash out if they are very light or very dark.

In studying the effects of quantity and quality of light sources and of backgrounds upon the perception of color we have used three methods: (1) colorimetric procedures in which observers were required to synthesize white, gray, black and various hues by manipulation of three primaries against strongly chromatic surrounds; (2) matching colored papers in a booth illuminated by one source (Illuminant A) with colored papers in a continguous booth illuminated by another source (Illuminant C) by looking alternately from one to the other; (3) reports by highly trained observers of the colors of papers while the observers were in a space illuminated by a single source (Macbeth daylight, or 6500K, 4500K, or 3500K fluorescent sources). Results by these three methods are in very good agreement and have yielded a number of generalizations regarding the effects of sources and surrounds on object colors.

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In the case of reflecting objects we can say that objects above adaptation-level are tinged with the hue of the illuminant while objects below adaptation level are tinged with the after image complementary hue to the illuminant. This effect is, of course, most striking in monochromatic illumination: a daylight gray paper of 7-15 per cent reflectance illuminated by monochromatic red light on black background is seen as red but on a white background it is a deep blue-green. This afterimage effect also occurs with as weakly chromatic sources as Illuminants A and B. It is often neglected in accounting for adaptation effects yet it is most important both for understanding the mechanism of vision and for predicting colors of objects if background effects on hue and chroma, as well as lightness, are to be taken into account. We have found that changes in reflectance of background are more important than changes in quantity or in spectral energy distributions of sources. In the case of luminous stimuli, their color is independent of surround if they are about 10 times brighter but they are markedly influenced by surround color if they are near or below surround luminance. A striking example of this is found in the change of color of a glowing cigarette tip from orange-red in ordinary light to green in ruby-red illumination. This pumping in of complementary color by the eye was most marked in our colorimetric studies also. Its importance was recognized by Ewald Hering who made it one of the corner stones of his theory of color vision. This effect is one of the main reasons why the C.I.E. method of color specification does not take account of effects of adaptation, particularly those due to chromatic surrounds.

Dr. Stiles mentions several sources of aesthetic enhancement due to vividness, sparkle and gloss of objects. To these we might add pronouncedness, location in the sense of advancing or retreating colors, hard-soft and warm-cold qualities, transparency, texture and possibly others. Some of these have already been measured and they are important for visual acuity as well as for their aesthetic effects. The evaluation of color rendering properties of light sources and their effects on people may have to take account of small changes in colors of object which, taken individually, do not amount to much, but when summed or totalled make for either acceptance or rejection of various types of illuminants for a variety of reasons among which aesthetic ones may be very important.

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H. Richard Blackwell

# The Problem of Specifying the Quantity and Quality of Illumination

THE PROBLEM of specifying the quantity and quality of illumination is a continuing concern of the Illuminating Engineering Society. It is apparent from a perusal of reports presented to the Society in the past that two principal bases have been used for establishing illumination specifications. These are visual performance and visual comfort. In his paper entitled "Visual Fatigue with Special Reference to Lighting," Weston has challenged us to re-evaluate our thinking with respect to visual comfort. In his paper entitled "Visual Factors in Lighting," Stiles has suggested that aesthetic pleasantness should be accepted as a third basis for specification of the quality of illumination. It seems to the author that the papers presented by our friends from abroad obligate us to undertake a comprehensive evaluation of our methods for specifying the quantity and quality of illumination. The present paper is not intended to represent a comprehensive evaluation, however, but merely to present certain general comments prompted by the Weston and Stiles papers.

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### Aesthetic Pleasantness

Unquestionably, illumination specifications must ultimately satisfy aesthetic criteria as well as criteria of adequate visual performance and comfort. The author feels, however, that aesthetic considerations are the proper concern of the architect, not the illuminating engineer. According to this view, the illuminating engineer establishes quantity and quality limits within which the architect may work, just as the structural engineer sets limitations on the structural materials and designs which may be used by the architect.

### Visual Comfort

It is entirely apparent that lighting installations must satisfy criteria of visual comfort. Although the importance of visual comfort is agreed upon, methods of evaluating comfort vary considerably among different investigators. Visual comfort is usually evaluated subjectively. The user of lighting feels able to judge the existence of visual discomfort and, to some extent, the degree of discomfort. Extreme discomfort is evidenced by objectively observable ocular symptoms. Since, however, few modern lighting installations will be sufficiently bad to produce such symptoms, we cannot expect to evaluate visual comfort frequently from analysis of ocular symptoms.

It is usually considered self-evident that subjective impressions of discomfort are valid indicators of "visual comfort." It will be well to analyze this notion, however, in view of Weston's paper. Weston has presented the view that visual discomfort must be associated with oculomotor phenomena such as the fatigue of the accommodative, ocular positioning, or pupillary musculature. This view has the unqualified support of modern neurology and physiology. In the discussion which follows, it will be convenient to refer to "sensory experience" and "kinaesthetic experience." By sensory experience we mean the subjective impression of light and light patterns, produced by light stimulation of the retina and the subsequent stimulation of the visual nervous system. By kinaesthetic experience we mean the subjective impression of the condition of the oculomotor musculature, produced by mechanical stimulation of receptors in the muscles and the subsequent stimulation of the kinaesthetic nervous system.

Our discussion of the validity of subjective impressions of discomfort will be more meaningful if we refer it to some actual measures of this kind. It will be convenient to discuss this question in terms of the measurements reported recently by Luckiesh and Guth.[1] The comments apply equally well to all subjective measurements of visual discomfort of which the author is aware. The Luckiesh-Guth data are selected principally because they are well known to illuminating engineers in this country.

Let us begin by reviewing the procedure employed in the Luckiesh-Guth experiments. These authors required their subjects to evaluate the discomfort produced by patches which differed in luminance from a visual field of otherwise uniform luminance. Two measurement methods were used, an absolute method and a comparison method. In the absolute method, the subjects were required to adjust the luminance of the patch to a subjective endpoint called the borderline between comfort and discomfort (BCD). This method was used to establish BCD values for each of three values of field luminance and for each of five sizes of patch at one field luminance. In the comparison method, a standard patch was set at the luminance which had already been established to be at BCD, and other patches were adjusted in luminance to produce an equivalent sensation of discomfort. The comparison method was used to evaluate the effect of patch position in the visual field, the effect of multiple sources, and the relative discomfort produced by linear and circular patches. The patches were presented intermittently for only a few seconds during each evaluation of the discomfort they produced.

Now, if we accept Weston's contention that discomfort is of oculomotor origin, it appears that the evaluations made by the subjects in the Luckiesh and Guth experiment were based upon either (a) kinaesthetic discomfort arising in the oculomotor musculature during the tests; or (b) an inference from the sensory experience of the field non-uniformity that kinaesthetic discomfort would arise in the oculomotor musculature if such a situation were continued long enough. If we accept the first alternative, we may inquire whether the kinaesthetic discomfort aroused by the patches in a few seconds are reliable indicators of the kinaesthetic discomfort which would result from prolonged realistic use of the eyes in the presence of such patches. "Realistic" use of the eyes involves continual changes in eye position, accommodation, and pupillary aperture for a prolonged period. The experimental situation used by Luckiesh and Guth involves little of this change, and only a brief time of use of the eyes. The author feels there to be reasonable doubt that any kinaesthetic discomfort aroused in the experimental situation will give an entirely reliable indication of the discomfort which will occur under the conditions of practical interest. The doubt exists for data collected with either the absolute or the comparison method.

The situation seems even less satisfactory if we believe that judgments of discomfort are based upon the second alternative. Here we are relying on the subject to have formed reliable impressions in the past of the relations between sensory experience of luminance non-uniformity and the kinaesthetic discomfort experienced when the eyes are used for a prolonged period in the presence of such non-uniformity. The author feels great doubt that reliable impressions of this sort are usually formed. Part of the difficulty originates in the fact that humans do not evaluate sensory experiences reliably. For example, it is possible to demonstrate by measurement that the sensitivity of the light-adapted eye varies by more than 50 to 1 as a point source is moved from the center of the visual field out to a point 12° from the center. And yet, if a point source is visible at first one and then another location in the visual field, it appears to have approximately equal subjective brightness. The author believes that the sensory effect of the point source varies in approximate inverse proportionality with the sensitivity from point to point. The source appears to have constant brightness in various locations, however, because the subject *knows that the source is physically constant.* Examples of subjective measurements which obviously depend upon the subjects' knowledge of the stimulus may be found without difficulty in the experimental literature. If subjects fail to evaluate sensory experiences reliably, but are influenced by their knowledge of the physical world, we may consider there to be reasonable doubt that subjects can reliably evaluate discomfort by inference from sensory experiences. This doubt applies to measurements made with either the absolute or the comparison method.

It is possible that an analogous difficulty exists even when subjective discomfort is evaluated under conditions of prolonged, realistic use of the eyes. In this case, presumably, there is a direct experience of muscular discomfort. However, the user of light may be unable to evaluate this experience without contamination from inferences as to the discomfort he expects on the basis of sensory experience. Presumably, this objection applies only when the experienced discomfort is mild; we would expect direct evaluation to be reasonably uncontaminated in the case of strong discomfort.

The foregoing discussion should at least remind us that we do not know precisely what subjects are judging when they evaluate visual discomfort in the Luckiesh-Guth type experiment. Until we have some better idea of the physiological or psychological basis of judgments of this kind, they must be viewed with caution.

We may well inquire to what extent other bases than subjective evaluations have been used for evaluating visual comfort. Moon and Spencer[2] have attempted to provide a theoretical framework for evaluating visual discomfort. These authors state that the sudden appearance of a luminance non-uniformity in the visual field causes a photochemical disequilibrium in the rods and cones. The photochemical disequilibrium triggers a temporary increase in the frequency of nerve impulses propagated along the optic nerve. Moon and Spencer assume that visual discomfort depends upon the difference in frequency of nerve firing produced by the presence of the luminance non-uniformity. Such an assumption places the origin of visual discomfort squarely in the visual sensory system, a view which is incompatible with Weston's view that visual discomfort must be of kinaesthetic origin. There appears to be no evidence to support the reasonableness of a sensory origin for discomfort. This leaves the Moon and Spencer formulation of discomfort in a very unsatisfactory state indeed.

How else can visual comfort be evaluated? It appears to the author that Weston has implied that the most logical measure of visual comfort is the evaluation of the condition of the oculomotor musculature under various lighting conditions. It is not entirely apparent just how this evaluation may best be accomplished. Perhaps it may be accomplished by testing the ability of the musculature to do further work, as is done in tests of accommodative and convergence fatigue. Perhaps it may be accomplished by evaluating the smoothness of performance of the musculature. For example, it would be possible to measure the smoothness of induced accommodative adjustments following prolonged use of the eyes in various light environments. It is suggested that developments of equipment and techniques along these lines be encouraged by the Illuminating Engineering Society.

### Visual Performance

It is interesting to note that Weston's paper was devoted exclusively to the problem of visual comfort. Weston's previous investigations of visual performance serve as the point of reference for most recent studies of this problem. Omission of a discussion of performance leads us to wonder if Weston considers the problem of specifying quantity and quality of illumination from performance data to be settled. The suggestion that Weston may consider this problem settled prompts the author to make the following comments with regard to performance data.

Visual performance may be measured in an entirely objective manner. Performance may be de-

fined meaningfully in terms of such variables as speed and accuracy. It is entirely straightforward in principle to measure speed and accuracy of visual performance as a function of quantity and quality of illumination. Such measurements could presumably be made for every visual task of practical interest. Unfortunately, the number of visual tasks which a human may be called upon to perform is virtually unlimited, if we consider tasks which differ from each other in any particular to be different tasks. Thus, the most obvious procedure of studying all possible visual tasks is entirely impracticable.

Two kinds of simplification have been suggested in the past. Weston[3] has simplified the problem by studying visual performance for a single visual task, which is assumed to be typical of visual tasks which are normally required of workers in industry. The task involves identifying the orientation of the break in a Landolt C, or broken-circle test object. The use of performance data for only one test object appears to the author to represent an undesirable oversimplification. There are sufficient data available in the experimental literature to demonstrate that visual performance of other tasks is not related to the quantity and quality of illumination in the same way as the task studied by Weston. Other limitations of Weston's study are discussed elsewhere,[4,5] and need not concern us here.

Moon and Spencer[6] have simplified the problem in a different manner. These authors apparently believe there to be two visual tasks of primary interest. The first of these involves the discrimination of the minimum perceptible contrast. Experimental conditions under which this discrimination is believed to be required include a large visual field of uniform luminance, and a circular test object subtending at least 1 degree. The second task involves "visual acuity"; the authors do not attempt an exact specification of the conditions under which this task is required.

Moon and Spencer present selected sets of data in which contrast discrimination and visual acuity thresholds are related to field luminance. Analytic curves are fitted through the selected data, of the form advocated by Hecht on the basis of the photochemical theory of vision. It is proposed that the analytic curves or expressions of the functional relations be used to specify the quantity of illumination, in a manner which need not concern us here. In a subsequent paper,[2] Moon and Spencer analyze the influence of luminance non-uniformity upon performance of these two visual tasks. Analytic expressions for these effects are combined with the original expressions to provide means of specifying quality as well as quantity of illumination.

The point to be made here is that Moon and Spencer have indulged in an analytic oversimplification of the problem. Visual tasks defy classification as either contrast discrimination or visual acuity. The literature contains numerous data in which performance does not relate to field luminance in the manner of the Moon and Spencer curves. Hence, specification of the quantity and quality of illumination on the basis of the Moon and Spencer curves or expressions must be considered inadequate.

How can we specify visual performance, if we reject the Weston method, and the Moon and Spencer method? The substitute the author proposes is the use of performance data for basic visual tasks. The position taken is that there are a comparatively few basic visual tasks, but considerably more than one or two. Practical visual tasks will usually represent principally one or another of these basic tasks.

Contemporary visual theory will suggest what some of the basic visual tasks may be. However, identification of the basic visual tasks will depend upon the demonstration that these tasks are relatively independent of one another, and that various practical visual tasks are equivalent to one or another of them.

An experimental demonstration of the independence of visual tasks presumed to be basic requires a study of the relations between performance of these tasks and quantity and quality of illumination. Tasks which exhibit equivalent functional relations between performance and quantity and quality of illumination are presumed to be equivalent. Tasks which exhibit basically dissimilar functional relations between performance and illumination variables are presumed to be independent.

The demonstration that practical visual tasks are equivalent to basic visual tasks requires that the performance of such practical visual tasks be studied in relation to the quantity and quality of illumination, and equivalence in the functional relations be established between the practical visual task and the basic visual task.

It may be well as this point to indicate what might conceivably be the basic visual tasks. The author believes that the most fundamental of the basic visual tasks is brightness discrimination. There can be no visual discrimination without the discrimination of luminance differences. When the task involves differentiating only the difference in luminance, we may call the task brightness discrimination. When the task involves differentiating that a difference in luminance occurred having a certain spatial pattern, we usually refer to the task as visual acuity. When the task involves differentiating that a difference in luminance occurred with a certain temporal pattern, we usually refer to the task as flicker sensitivity. Depth discrimina-

tion involves differentiating that a difference in luminance with a certain spatial pattern occurred differentially between the two eyes. Color discrimination may involve no more than differentiation that a luminance difference occurred with a certain discontinuous spatial pattern corresponding to the distribution of color receptors of different spectral sensitivities.

This list may well represent the major divisions among basic visual tasks. However, each of the visual tasks in the list may be expected to have important sub-divisions. For example, brightness discrimination depends upon size and shape of test object. We may expect that the relations between performance and quantity and quality of illumination will differ in important ways for brightness discriminations of test objects differing in size and shape. Data presented elsewhere by the author[5] demonstrate that the relation between performance and quantity of illumination differs in important ways as test object size is varied. Demonstration of similar differences with target shape awaits new experimentation, as does demonstration of the differential effects of size and shape of test object in the presence of luminance non-uniformity.

It is to be noted that Moon and Spencer[6] regard contrast (brightness) discrimination as *one* visual task, and are content to write one expression for the relation between performance of this task and field luminance. The view taken here is that brightness discrimination is a class of tasks which differ from other tasks in the extent of information required for performance. The relation between performance of brightness discrimination and field luminance, however, is by no means constant, and hence one expression is by no means a satisfactory description of the facts of brightness discrimination.

Let us assume that we will finally establish a list of basic visual tasks and will have complete information relating performance of each of these tasks to the quantity and quality of illumination. We may wonder in what way the illuminating engineer would use this information in establishing specifications for quantity and quality of illumination in practice. The author proposes that the illuminating engineer would have to develop means of identifying practical visual tasks with one or another of the basic visual tasks. One useful procedure would involve studying the relation between performance and quantity of illumination for practical tasks with some kind of visibility or contrast meter. The form of the relation between performance and quantity of illumination for the practical task should suggest identification with one or another basic task. The complete data for the basic task on the relations of speed and accuracy to quantity and quality of ilumination could be applied to the practical situation once the identification was made.

The author does not presume to suggest further means by which the illuminating engineer will manage to identify practical tasks with the basic visual tasks. He does have great confidence, however, that illuminating engineers will find a way to make such identifications practical.

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## DISCUSSION

H. C. WESTON*: Dr. Blackwell's paper is characteristically thoughtful. However, his proposal that basic visual tasks be studied and relations be determined between performance of those tasks and "quantity and quality of illumination" seems identical with that made by Beuttell[1] which stimulated my own studies. The basic task used involved discrimination of luminance difference occurring as in the second of the basic tasks indicated by Dr. Blackwell. With this basic task overwhelming majority of practical tasks can be identified. Doubtless more complete basic data can be obtained and it may be that when these are available specifications of "quantity of illumination" can be made less equivocal than at present. Meanwhile, it is important to agree upon what *kind* of data the specification of illumination levels for specific visual tasks should be based, and Dr. Blackwell evidently shares my view that visual performance data are most appropriate. There seems no good reason why existing data of this kind should not be generally used pending the acquisition of more reliable or more complete data. As Dr. Blackwell points out, basic data of the kind under discussion can only be applied by the illuminating engineer if he develops means of identifying practical visual tasks with basic tasks. I have discussed this identification, or task analysis, elsewhere[2] and pointed out how difficult it will sometimes be. It is a discipline which the "scientific" illuminating engineer must accept, but, having made the analysis of various practical visual tasks, these can be scheduled with their respective adequate values of illumination, as is now done on a more empirical basis in current "recommended practices."

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Glenn A. Fry

# A Re-Evaluation of the Scattering Theory of Glare

## Introduction

Stiles[1] pointed out two fundamental objections to the hypothesis that the effect of a glare source on foveal vision can be attributed to stray light in the eye.

(1) On the one hand, he found that in order to account for the effect, it was necessary to assume more light scattered than was known to be lost in the transmission process through the media of the eye.

(2) He also showed that the equation for stray light derived from theory, did not conform to the effect produced by a peripheral glare source.

Since Stiles did his study, more exact information about the transmission of the ocular media has become available and it is known that the transmission of the human eye is lower than that assumed by Stiles.

Furthermore whereas Stiles assumed as Holladay[2] had done that the scattering of the media of the eye conforms to Rayleigh scattering, which makes the amount of scattering inversely proportional to fourth power of the wavelength, it has been found since then that the effect of a glare source is more or less independent of the wavelength of light.[3] This suggests that the scattering particles have a diameter greater than the wavelength of light. If this is the case, one can assume a greater preponderance of forward scattering and thus bring the scattering theory into closer agreement with the facts.

In the present paper, a scattering function has been selected which has a high predominance of forward scattering and with this it can be demonstrated that the amount of light which must be assumed to be lost by scatter does not exceed the total amount of light which is known to be attenuated by the media.

Furthermore, an effort has been made to discover what further modifications have to be made in the theory to bring it into complete agreement with the facts.

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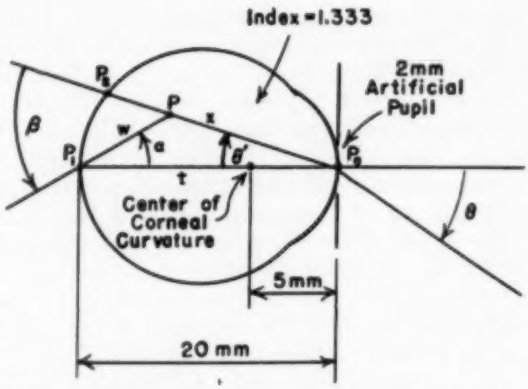


**Figure 1. Reduced eye used in computing scattered light in the eye.**

## The Scattering Theory of Glare

The theory of scattering may be stated as follows: To simplify calculations a reduced eye has been used and the pupil has been assumed to lie in the plane of the cornea as shown in Fig. 1. It has been assumed that the medium is uniform in its scattering characteristics from the cornea to the retina.

In Fig. 1 rays from a glare source at an angle $\theta$ from the optic axis focus at the retina. It is assumed that the stray light from this source falling at the fovea is due to first order scatter by the medium along the beam between the cornea and the retina, and that the stray light produced by flare, reflection at the retina and other sources is negligible.

It is further assumed that the amount of scatter is independent of the wavelength.

The flux $F_e$ (lumens) entering the pupil is

$$F_e = E_e A_e (1 - \rho) \qquad (1)$$

where $E_e$ is the illuminance (lumens per square meter) in the plane of the pupil and $A_e$ is the area (square meters) of the pupil and $\rho$ is the fraction of light lost by reflection at the front surface of the cornea. The flux $F$ passing through a cross section

of the beam at any point $P$ on the axis of the beam is the same as that entering the pupil except for the loss by attenuation,

$$F = F_o e^{-x\sigma} \tag{2}$$

where $e$ = the Naperian base,
$x$ = the distance $P_oP$ in meters, and
$\sigma$ = the attenuation coefficient of the medium.

When the beam traverses a distance $dx$ through the medium of the eye starting at the point $P$, a certain fraction of the incident flux is scattered in the direction of $P_1$ at an angle $\beta$ from the axis of the beam. This scattering makes the point $P$ equivalent to a point source and the candle power in the direction of $P_1$ is given by the following equation:

$$dI = F \phi \, dx \tag{3}$$

where the scattering function $\phi$ is a function of the angular displacement $\beta$ of the direction of scatter from the forward direction and is given by the following equation:

$$\phi = R \cos^2 \beta \tag{4}$$

for values of $\phi$ between zero and $(\frac{1}{2})\pi$ radians. Backward scattering is not involved in first order scatter, and it has been assumed that the scatter is zero for angles between $(\frac{1}{2})\pi$ and $\pi$.

In Fig. 2, the scattering function defined by Equation (4) is compared with the Rayleigh scattering function. The forward scattering is much more pronounced for the scattering function in Equation (4) than for Rayleigh scattering. A considerable amount of information about scattering functions for particles for different types and sizes has been summarized by Hulburt.[4] Equation (4) is not a theoretical curve for particles of a given size or shape but, is comparable to scattering functions for particles larger than the wavelength of light and has the advantage of being easy to work with.

The illuminance $dE$ at $P_1$ in the plane of the retina is given by the following equation

$$dE = \frac{F \phi e^{-w\sigma} \cos \alpha \, dx}{w^2} \tag{5}$$

where $w$ is the distance (meters) from $P$ to $P_1$,
where $e^{-w\sigma}$ is the fraction of the beam transmitted by the medium, and
where $\alpha$ is the angle of incidence at the retina.
Substituting $F_o (e^{-x\sigma})$ for $F$. [See Equation (2)],

$$dE = \frac{F_o (e^{-x\sigma}) (e^{-w\sigma}) \phi \cos \alpha \, dx}{w^2}. \tag{6}$$

For small values of $\theta'$ it may be assumed that

$$e^{-w\sigma} \cdot e^{-x\sigma} = e^{-(x+w)\sigma} = e^{-t\sigma} = (1 - \gamma)$$

where $t$, $w$, and $x$ are expressed in meters and where $\gamma$ represents the fraction of light lost by

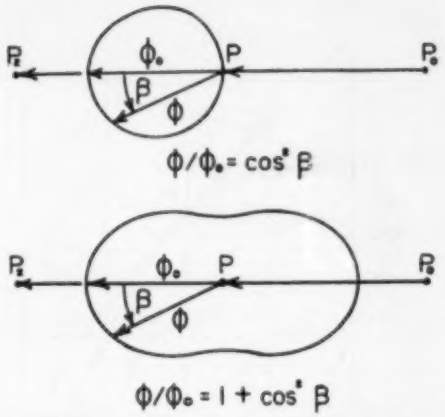


**Figure 2. Comparison of scattering functions.**

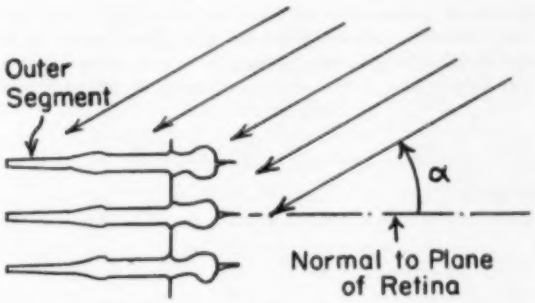


**Figure 3. Relation of the angle of incidence to the absorption of light by the photoreceptors.**

attenuation,
and hence

$$dE = \frac{F_o (1 - \gamma) \phi \cos \alpha \, dx}{w^2}. \tag{7}$$

This equation gives illuminance in the plane of the retina which is proportional to the cosine of the angle of incidence ($\cos \alpha$). However, it is not very likely that the amount of light absorbed by the photoreceptors at $P$ is proportional to the cosine of the angle of incidence. It is known for example from the Stiles-Crawford effect that this is not always the case. The theory of scattering will have to be modified at this point when the facts are known. Fig. 3 illustrates the nature of the problem. The photosensitive substance lines the inside of the outer members of the cones. The problem is further complicated by the extension of processes from the pigment epithelium between the photoreceptors.

Integrating to determine the illuminance $E$ at $P_1$ in the plane of the retina:

$$E = F_o (1 - \gamma) \int_0^{t \cos \theta'} \frac{\phi \cos \alpha \, dx}{w^2} \, . \tag{8}$$

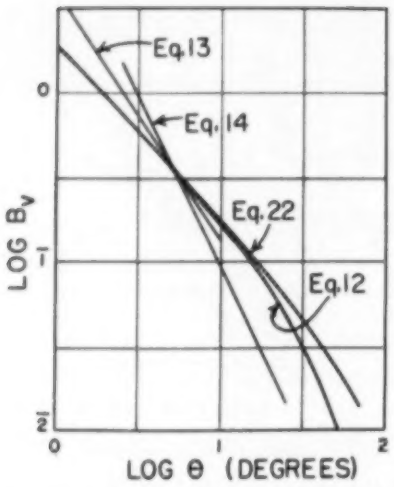


**Figure 4. Comparison of the theoretical [Eqs. (12) and 22)] and experimental [Eqs. (13) and (14)] values of $B_v$ for various values of $\theta$. Values for $R$ have been selected for Equations (12) and (22) which make all of the curves cross at $\theta = 5°$.**

Since

$$\frac{t \sin\theta' \, d\beta}{\sin^2 \beta} = dx$$

and

$$w^2 \sin^2 \beta = t^2 \sin^2 \theta',$$

and since

$$x = \beta - \theta',$$

Equation (8) reduces to

$$E = \frac{F_o (1-\gamma)}{t \sin\theta'} \int_0^{\pi/2} \phi \cos x \, d\beta$$

$$= \frac{2F_o (1-\gamma) R}{3t} (\cot\theta' - \cos\theta'). \tag{9}$$

Substituting $\frac{\theta}{n}$ for $\theta'$, and $E_o A_o (1-\rho)$ for $F_o$ [See Equation (1)],

$$E = \frac{\frac{2}{3} E_o A_o (1-\rho) (1-\gamma) R}{t} \left( \cot\frac{\theta}{n} - \cos\frac{\theta}{n} \right) \tag{10}$$

## Experimental Determination of $R$

The luminance $B_v$ (candles per square meter) of a uniform patch of light which would be required to produce an equivalent amount of retinal illuminance $E$ (lumens per square meter) is given by the following equation:

$$E = \frac{B_v A \rho (1-\rho) (1-\gamma) n^2}{t^2}. \tag{11}$$

It follows from Equations (10) and (11) that

$$B_v = \frac{2}{3} \frac{t}{n^2} E_o R \left( \cot\frac{\theta}{n} - \cos\frac{\theta}{n} \right). \tag{12}$$

On the assumption that the effect of a peripheral glare source on the luminance difference threshold at the fovea is mediated by stray light, one can determine the value of $B_v$ experimentally for a given glare source by finding out how much veiling luminance $B_v$ is required to interfere with visibility to the same degree as the glare source. Stiles investigated this effect for values of $\theta$ between 1 and 10, and found the following equation to hold:

$$B_v = \frac{4.16 E_o}{\theta^{1.5}}. \tag{13}$$

In this equation, $\theta$ is expressed in degrees, $B_v$ in candles per square meter and $E_o$ in lumens per square meter. Holladay investigated the range from 2.5° to 25° and found the following equation to hold:

$$B_v = \frac{9.2 E_o}{\theta^2} \tag{14}$$

These two equations are plotted as straight lines in Fig. 4. They cross at $\theta = 5°$, $B_v = 0.363$, when $E_o$ is equal to unity. Substituting these values of $E_o$, $B_v$ and $\theta$ into Equation (12), we obtain a value of 3.39 for $R$ when $t$ is expressed in meters.

It should be noted that $E$ in Equation (11) includes only the light which is transmitted without scatter and does not include the stray light in the eye produced by the uniform patch of light. By not including this stray light a small amount of error is introduced into the calculation of $R$.

## Heterochromatic Glare Sources

Equations (10), (11) and (12) will apply strictly to monochromatic light, if $(1-\gamma)(1-\rho)$ represents the transmittance of the eye for a given wavelength and if $n$ also represents the index for a given wavelength.

In the case of heterochromatic light the transmittance may be defined as follows:

$$(1-\gamma)(1-\rho) = \frac{1}{E_o} \int_0^\infty (E_o)_\lambda (1-\gamma)_\lambda (1-\rho)_\lambda \, d\lambda \tag{15}$$

where $(E_o)_\lambda$ represents illuminance in the plane of the pupil per unit wavelength $\lambda$ and $E_o$ represents the total illuminance in the same plane.

The index $n$ is also a function of wavelength but little error is introduced into the calculations if $n$ is assumed to be constant at 1.333.

### The Attenuation Coefficient ($\sigma$) of the Media of the Eye

A theoretical value for $\sigma$ can be computed from the scattering function $\phi$ as shown below provided it is assumed that the attenuation is due to scattering. When a beam traverses a distance $dx$ through the medium of the eye starting at the point $P$, a certain fraction of the incident flux $dF_s/F$ is scattered.

$$\frac{dF_s}{F} = \sigma\, dx. \tag{16}$$

This scattering makes the point $P$ equivalent to a point source emitting light in all directions. The candle power $dI$ in any given direction is given by the following equation,

$$dI = F\,\phi\, dx, \tag{17}$$

where the scattering function $\phi$ is a function of the angular displacement $\beta$ of the direction of scatter from the forward direction.

The total flux $dF_s$ scattered in all directions is given by the following equation:

$$dF_s = 2\pi F\, dx \int_0^{\pi} \phi \sin\beta\, d\beta. \tag{18}$$

It follows therefore from Equations (16) and (18) that

$$\sigma = 2\pi \int_0^{\pi} \phi \sin\beta\, d\beta. \tag{19}$$

Substituting $R\cos^2\beta$ for $\phi$ we obtain

$$\sigma = \tfrac{2}{3}\pi R = 7.10 \tag{20}$$

when $x$ is expressed in meters.

### Transmission of the Ocular Media

Assuming that all of the light lost in the process of transmission from the cornea to the retina is lost by attenuation one can compute a value for $(1-\gamma)$ as follows:

$$1-\gamma = e^{-\sigma t} = 0.867 \tag{21}$$

Fig. 5 shows the Ludvigh-McCarthy[7] data for the transmittance $(1-\gamma)$ of the ocular media for various wavelengths $(\lambda)$. It is obvious that even at the red end of the spectrum where the transmission is at a maximum, approximately 30% of the light is attenuated. This amount of attenuation can account not only for the forward scatter (13.3%) but also for light lost by reflection at the refracting surfaces, backward scatter and absorption.

It may be concluded that the light which we have to assume to be lost by scatter does not exceed the total amount of light which is known to be attenuated.

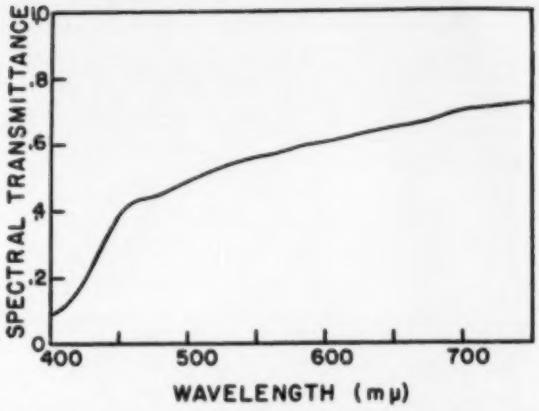


Figure 5. Ludvigh-McCarthy values for the transmittance of the ocular media for the various wavelengths.

### Agreement Between the Theoretical and Empirical Curves for $B_v$

A curve representing Equation (12) is plotted in Fig. 4 to compare this theoretical curve with the empirical curves for $B_v$. The agreement is somewhat better than that obtained for Rayleigh scattering which is represented by the following equation:

$$B_v = .0246\left(\cot\frac{\theta}{n} - \frac{2}{5}\cos\frac{\theta}{n}\right) \tag{22}$$

However, it is not as good as it ought to be. The constant has been selected so that $B_v = 0.363$ when $\theta = 5$ and $E_o =$ unity.

It would appear that complete agreement cannot be achieved merely by changing the form of the scattering function, or by making a different assumption about how the absorption of light by photoreceptors is affected by the angle of incidence.

It has been assumed that the medium of the eye is uniform from the cornea to the retina. This is only an approximation. It is known that the lens for example has a much higher attenuation coefficient than the aqueous or the vitreous. So far as the lens is concerned the values of both $\alpha$ and $\beta$ are small for first order scattering and the scattering function determines for the most part the distribution of light on the retina. If the lens alone were considered, it would be necessary to assume an unreasonable amount of forward scatter. Hence all of the media of the eye should be considered with different scattering functions and attenuation coefficients for each. This gives the scattering theory the flexibility it needs to bring it within range of experimental facts and permits one to make whatever assumption that needs to be made in regard to

the effect of angle of incidence upon the light absorbed by a photoreceptor. It seems unnecessary therefore to postulate a mechanism in the retina to help account for the effect of a peripheral glare source on foveal vision, except in the case of glare angles of two degrees or more.

### Computation of Stray Light in the Eye for a Distribution of Luminance in the Field of View

Although a completely adequate theory cannot be formulated at the present time, it is possible to use the theory to arrive at a means of extrapolating the Stiles and Holladay equations to a zero value of $\theta$. This is necessary to compute the stray light at the fovea produced by a given distribution of luminance in the field of view.

The assumption of almost any reasonable scattering function has led to the proposition that $B_v$ is proportional to $1/\theta$ for small values of $\theta$. The following equation

$$B_v = \frac{9.2\,E}{\theta\,(1.5+\theta)} \qquad (23)$$

where $\theta$ is expressed in degrees, makes $B_v$ proportional to $1/\theta$ for small values of $\theta$ and also fits reasonably well the data for both Stiles and Holladay (Fig. 6). For large values of $\theta$, it is equivalent to Holladay's equation.

If $\theta$ is expressed in radians instead of degrees, Equation (23) may be rewritten as follows:

$$B_v = \frac{9.2}{(57.3)\,(1.5)}\,\frac{E}{\theta\,(1+38.2\,\theta)}. \qquad (24)$$

If we define direction in the field of view of the reduced eye in Fig. 1 in terms of the half-meridian $\phi$ and the angle of eccentricity $\theta$, the illumination in the plane of the pupil $dE$ produced by the luminance $B$ in a given direction is given by the following equation:

$$dE = B\cos\theta\sin\theta\,d\theta\,d\phi$$

where

$\cos\theta$ = cosine of the angle of incidence in the plane of the pupil, and

$\sin\theta\,d\theta\,d\phi$ = an element of solid angle.

Substituting this into Equation (24) and integrating for the entire field of view, we obtain:

$$B_v = \frac{9.2}{(57.3)\,(1.5)}\int_0^{2\pi}\int_0^{\pi/2}\frac{B\cos\theta\sin\theta\,d\theta\,d\phi}{\theta\,(1+38.2\,\theta)}. \qquad (25)$$

For the special case of a uniform circular patch of luminance concentric with the axis of the eye, and having a radius equal to $\theta$, Equation (25) reduces to

$$B_v = \frac{18.4\,\pi\,B}{(57.3)\,(1.5)}\int_0^{\theta}\frac{\cos\theta\sin\theta\,d\theta}{\theta\,(1+38.2\,\theta)} \qquad (26)$$

and if one substitutes $\sin\theta$ for $\theta$ which holds for small values of $\theta$, Equation (26) reduces further to

$$B_v = \frac{18.4}{(57.3)^2}\,\pi\,B\log_e(1+38.2\sin\theta). \qquad (27)$$

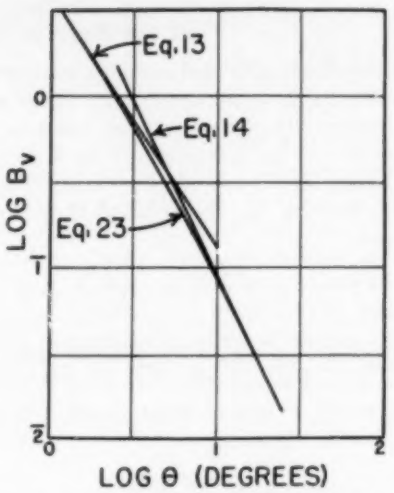


**Figure 6. A curve which fits reasonably well with the Holladay and the Stiles values for $B_v$ as a function of $\theta$ and extends to a zero value of $\theta$ on the basis of theory.**

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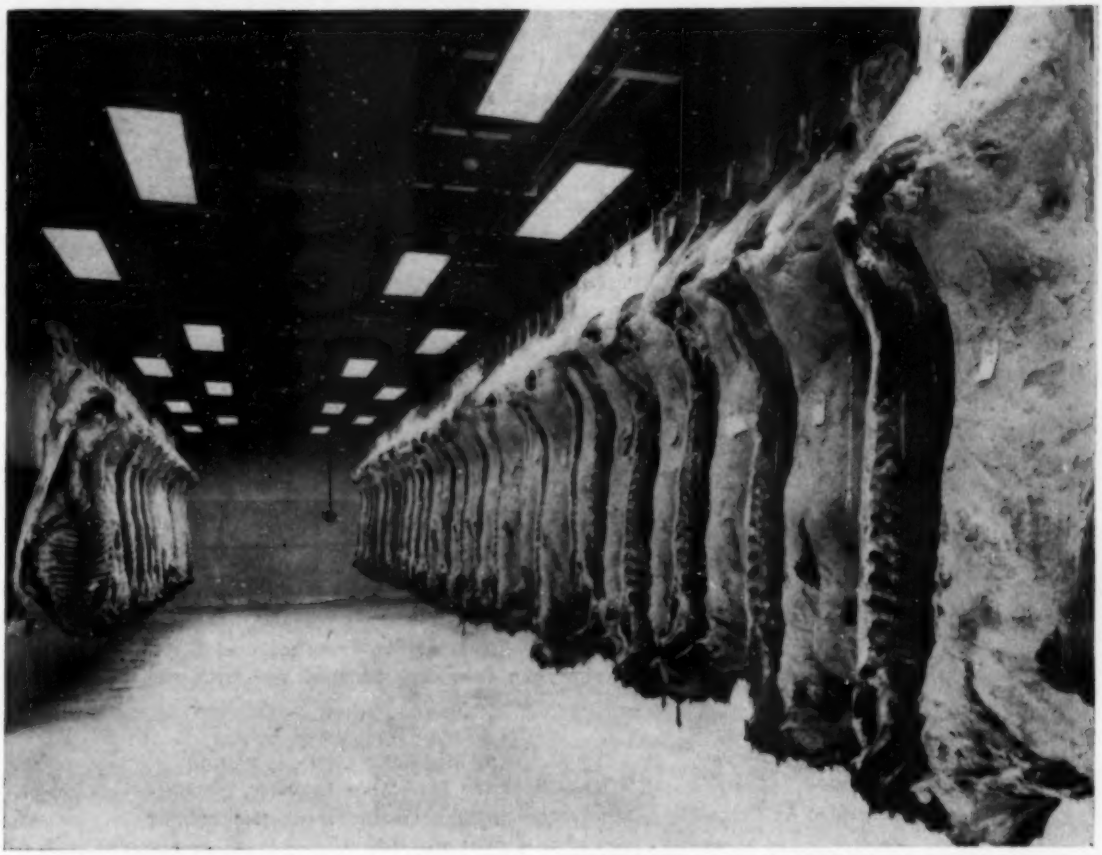

INSTALLATION AT JAMES ALLAN PACKING COMPANY, SAN FRANCISCO, CALIFORNIA.

# Lighting a Meat Grading & Inspection Room

**LIGHTING OBJECTIVE:** To provide well distributed general lighting that renders a natural appearance to the meat so it can be inspected and graded, with a minimum of heat produced by the lighting system.

**GENERAL INFORMATION:** Inspection and grading of beef at a temperature of from 30F to 32F is carried on in this 22′ 6″ x 93′ 0″ chilling room. For easy movement the meat is hung from trolley tracks located on the ceiling. Fluorescent lighting was preferred to incandescent filament lamps because it would add less heat to the room.

**LIGHTING INSTALLATION:** General direct illumination is provided by Westinghouse 2FDT-40 vapor-tight luminaires. The units, each containing two 40-watt lamps, are mounted 11 feet above the floor on 7-foot centers down the length of the rows. Satisfactory operation with standard fluorescent lamps and standard ballasts has been reported by the Allan Packing Company. Both company officials and employees report that the appearance of the meat under soft white lamps is enhanced and the "choice" beef looks "choice" and is graded as such by the inspectors.

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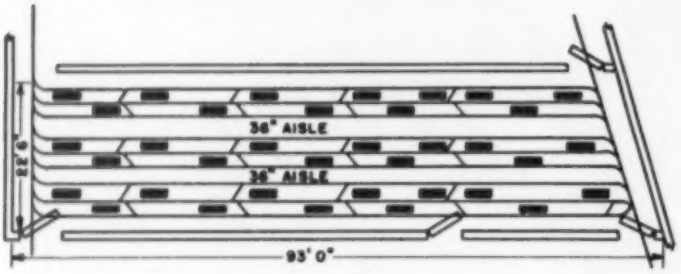


Figure 2. Plan view showing luminaire spacing.

Illumination levels measured on the vertical surface of a typical carcass after 600 hours' operation are as follows:

| Distance above floor, feet | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|
| Footcandles | 10 | 12 | 13 | 15 | 17 | 19 | 22 | 30 |

**R. W. Holman, Westinghouse Electric Supply Company, San Francisco, and C. N. Holobar, Marine Electric Company, San Francisco, designed and made the installation.**

**Lighting data submitted by George P. Leyes, Lighting Application Engineer, Westinghouse Electric Corporation, San Francisco, as an illustration of good lighting practice and to aid in the design of similar installations.**

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# Taste Testing Rooms . . . .

## Lighting for Food Technology

**Booths for taste-testing cake samples from prepared cake mixes present rather unusual lighting problems. To minimize the effect of appearance on the appetite, low levels are required; at the same time high levels of illumination are needed for visual inspection and record keeping. How the authors solved this application problem is told in the following article.**

By HARRY W. SPELL
A. W. LANGE

HOW DO you like your chocolate cake? Dark, medium or light? Food companies have quite a job turning out products which will please customers who have different likes and dislikes. To please most of the people most of the time is the job of the food industry, and in order to keep the American consumer coming back for more food, companies have turned to product evaluation and acceptance tests.

The authors faced the problem of proper lighting of a taste testing room located at the General Mills Research Division in Minneapolis, Minnesota. It is here that General Mills compares cake mixes, cereals and other food products. Here General Mills cake mixes and competitive brands are prepared under exacting conditions, cut into identical slices, labeled, and placed in testing booths as shown in photo. Professional food testers, each seated in individual testing booths then examine the samples as to visual quality, taste and smell.

The lighting problem is dual, requiring a solution for both very low levels to provide scotopic (rod) vision and a very high level for maximum visual acuity and performance.

In the first case, the food testers desire to reduce the effect of color and appearance on taste. Chocolate cake samples, for example, of different brands have different appearances, as to hue and textures. In certain test procedures tastes and smell only are being compared, and to neutralize the effect of appearance on appetite, taste or smell, it is necessary to reduce illumination until field brightnesses are about .01 footlambert, for at this level the eye is operating on rod vision and color differences are not distinguishable. Thus, by low illumination, and surround treatment in neutral grays, a neutral test environment is established to isolate the taste sense as much as possible. Under such low levels of illumination, the chocolate cake samples from several sources would be virtually indistinguishable and a true taste test can be obtained. The low level problem includes the lighting of recording sheets placed near the samples, on which testers record their reaction to food samples. Illumination on the score sheet must be sufficient to permit testers to read instructions usually mimeographed or typewritten on white paper.

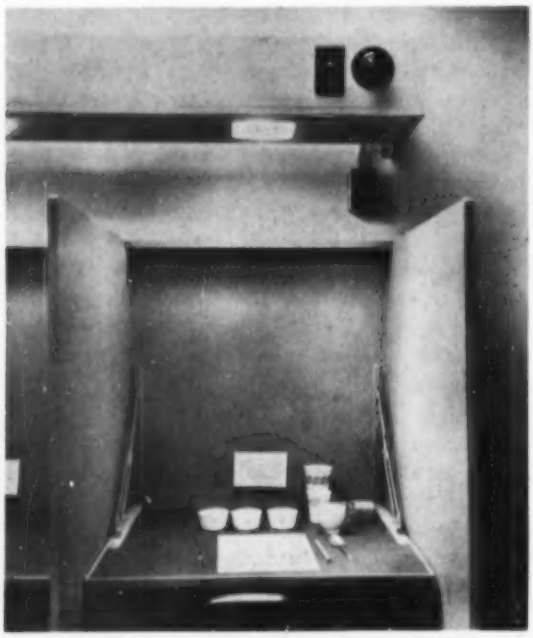
The high level of illumination is required for other phases of food taste testing and for the visual inspection of several brands and for taste tests including all variables of appearance, hue, texture and their subjective effects on taste. The lighting equipment should be comfortable and unobtrusive, free from glare or excessive brightness, yet capable of producing about 200 footcandles or better to place the observers on the "plateau" of the performance and acuity curves. The tasters should be able to perceive minute color differences, texture differences and compare physical appearance of the

This installation won second place in the Twin Cities Section "My Most Interesting Lighting Job" contest for 1953. AUTHORS: Lighting Engineer, Northern States Power Co., and District Engineer, Holophane Co., Inc., Minneapolis, respectively.

Layout of taste-testing room. Entrance is through door at left. Sliding door separates food preparation and work area from the room where actual testing is done. Sketch by Cliff Abrahamson, who helped plan and design room.

food samples. This combined taste, smell and visual test combines three senses and is important in final stages of product development when color, texture and taste are being compared.

Providing the solution for very low levels of illumination, lighting units were mounted directly above each booth, four feet from the table top. A concentrating type recessed incandescent lens unit with 60-watt clear lamp is used. The concentrated beam is directed on the testing questionnaire sheet providing enough illumination on the questionnaire for reading and writing, the spill light at the same time providing the minimum illumination for the samples.



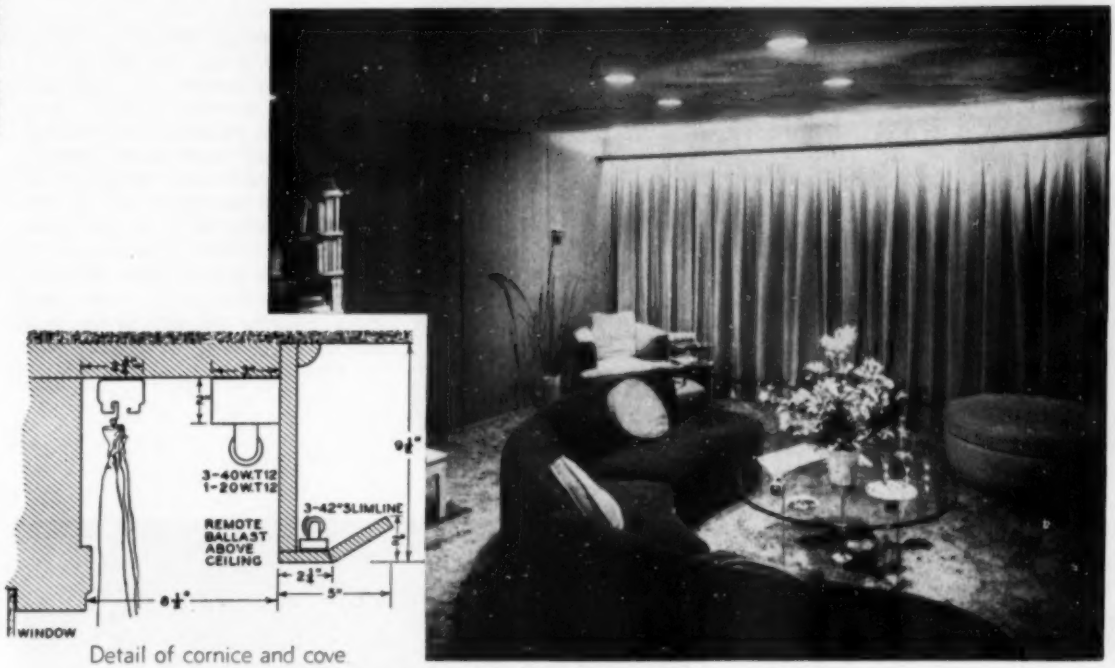
Typical taste testing booth showing food samples, score sheet, and concentrating type prismatic lens units controlled by variac. Illumination is varied from 0.1 to 50 ft-c, depending on product and type of test.

These concentrating lens units are all centrally controlled by one variac located in panel above the recessed units. By various settings of the variac control, illumination is varied from a bare glow in the filaments to full level. Through trial and error the food technologists have determined settings on the variac for testing the various products. After the above tests have been made and recorded, study and comparison of texture, color and general physical appearance is required. For this seeing task a high level of general illumination including full brightness from the booth lighting is necessary. Lighting is provided by two eight-foot, four-lamp slimline low-brightness lens units. The units are equipped with prismatic lenses with an intensive distribution but yet maintain an excellent brightness control. For greater flexibility of the system, two lamps of each fixture have been switched independently.

## Conclusion

The lighting solution meets the requirements of the taste test laboratory and solves the problem presented. It is a straight-forward application of basic illumination engineering data. The reaction of the personnel using the room has been enthusiastic and verifies the original analysis of the problem and its consequent proper solution.

The authors are indebted to Mr. C. Abrahamson, of General Mills Research Laboratories, Minneapolis, for his cooperation to the solution of this problem and his cooperation in permitting use of the lighting data to enable other food processors to design similar lighting installations.




Detail of cornice and cove

INSTALLATION IN CLEVELAND HEIGHTS, OHIO.

# Lighting a Window Wall

**LIGHTING OBJECTIVE:** To provide both upward and downward lighting at a living room window having ceiling to floor draperies.

**GENERAL INFORMATION:** This 20 x 33 foot living-dining room has white plastered ceilings 8 feet high, walls paneled in Philippine mahogany, and blue-gray carpeted floors. Reflectances are approximately 70, 30 and 20 per cent respectively. All local lighting in the room is provided by means of 150-watt reflector flood lamps in louvered recessed luminaires. To maintain comfortable brightness ratios it was necessary to provide as much general lighting as possible by means of light reflected from walls and ceiling. Windows at each end of the room were draped from ceiling to floor with 55 per cent reflectance gray faille.

**INSTALLATION:** A special custom-built combination cornice and cove was built over both windows so that light could be reflected from the ceiling as well as from the draperies. The 9½-inch deep wall-to-wall cornices of Philippine mahogany (as deep as it was felt they could be from the architectural viewpoint) were built 8½ inches out from the wall in order to illuminate the very billowy draperies as evenly as possible. Deluxe cool white fluorescent lamps were used in the cornice.

To the bottom edge of the cornice was attached a very shallow cove (see line drawing), housing three deluxe cool white T6 slimline lamps operated at 120 ma. This serves to spread some light on the ceiling and to illuminate the cornice faceboard to a brightness of 25 footlamberts. The brightness of the fabric just below the cornice is 50 footlamberts. The ceiling varies between 48 footlamberts just above the cove to 5 footlamberts four feet away from the wall.

**Architect: George A. Letts, Cleveland, Ohio.**

**Lighting data submitted by Miss Aileen Page, Residence Lighting Specialist, General Electric Lamp Division, Nela Park, Cleveland, Ohio, as one solution to a lighting problem and to aid in the design of similar installations.**

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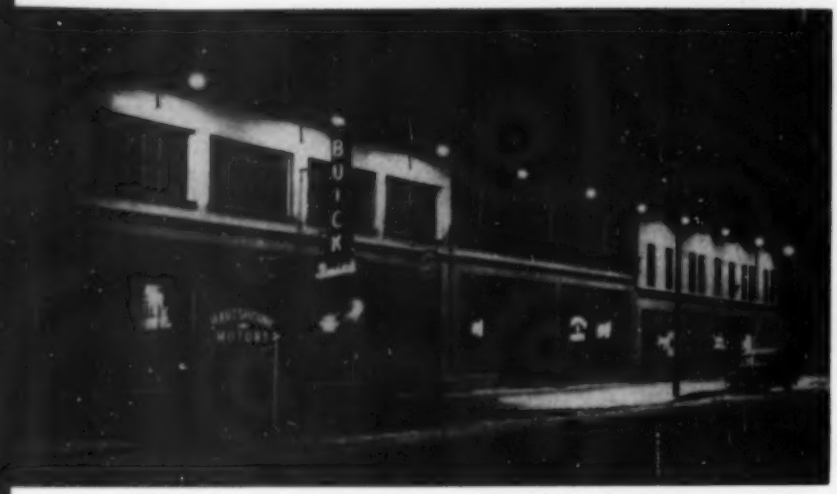


At the Hartshorne Motors in Chicago, ten modified Type IV floodlighting luminaires are mounted on hinged wall brackets for servicing from the roof. The units are equipped with color-corrected mercury vapor lamps, and are mounted 25 feet above the ground, 15 feet in from each end, and 30 feet apart, extending out 5 feet 6 inches from the wall. Overall illumination is approximately 10 footcandles. Note the special bracketing on the three center units. Aligning the units at one level provides very even illumination over the whole area.

Montgomery Motors Oldsmobile Co., Chicago. This corner building has mercury vapor floodlighting luminaires using J-type color-improved lamps, mounted on hinged wall brackets so that the units may be readily serviced from the windows. The units are mounted 30 feet above the ground and 32 feet apart, extending out 5 feet 6 inches from the building wall. Overall illumination is approximately 8 footcandles.

Kungsholm Restaurant, Chicago. Certain building facades such as Kungsholm Restaurant, require a specially designed period type bracket in keeping with the architecture. Modern, high-level mercury vapor lamps, of the J-type color-corrected types, have been used in such a design, with units mounted 14 feet 6 inches from the ground and extending 3 feet 6 inches from the wall. Approximately 14 footcandles illumination is provided around the sidewalk area.

**Pictures and data supplied by N. E. Passman, Nepo Manufacturing Company, Chicago, Illinois, through the Chicago Section Papers Committee.**

A typical installation in Skillern's Shopping Center, Garland, Texas. Mercury vapor floodlighting luminaires using E-H1 lamps are mounted 30 feet above the ground and 85 feet apart. Overall illumination is approximately 2.5 footcandles.

# Outdoor Store Lighting With Mercury Vapor

**Store front lighting has, during the past year or two, become a major merchandising tool. Merchants have felt that its benefits have been several-fold — for customer attraction, for night advertising, for protection and for parking. Using mercury vapor lamps, in most cases color corrected types, several such installations are shown on this and the facing page.**

People's Pontiac, Chicago, Illinois. In line with the trend toward better outdoor lighting, this company has installed mercury vapor luminaires across their entire store front. Type J-H1 lamps are used for color improvement. The floodlighting luminaires are mounted on hinged brackets for easy maintenance. Twenty units are used, 25 feet above the ground and 27 feet apart, to provide 11 footcandles over the area.

# Effect of Temperature on Fluorescent Street Lighting Luminaires

By J. E. BOCK
J. S. FRANKLIN

FLUORESCENT LAMPS are unique among present day light sources, used in enclosed street lighting luminaires, in their sensitivity to the ambient temperature. Incandescent lamps with their extremely high filament temperatures; mercury arc lamps with an outer jacket enclosing the inner jacket; and the vacuum flasks around sodium lamps, protect these lamps from wide fluctuations in light output as the ambient temperature varies. At the present time, fluorescent lamps are not so fortunate; so for outdoor applications, such as in street lighting luminaires, it was imperative that information be available on the variation in light output with ambient temperature.

There are many factors, other than temperature, that affect the light output, and to one degree or another they have been studied. The temperature characteristic, however, because of its pronounced effect, has received our greatest attention to date. Long range studies of some of the other factors are in progress, but results will not be known for some time to come.

Just what are these factors? To generalize, the particular construction and normal operation conditions of the luminaire and lamps employed are of major importance, and include such factors as:

1. Luminaire construction
2. Type of lamps
3. Lamp current
4. Number of lamps per luminaire
5. Ballast location

These factors are fixed, once a particular luminaire has been put into production. Thereafter, the next in importance are factors such as:

1. Ambient temperature
2. Rate of change of ambient temperature
3. Physical location of the street lighting installation within or without the boundaries of the United States of America
4. Surface wind velocity and direction
5. Rain and snowfall

Although these are factors over which we have no control, the ultimate user nevertheless expects a satisfactory lighting job regardless of these variations.

Predicting future photometric performance of fluorescent luminaires is made possible by knowledge gained through a study of these various factors. This paper presents, among other things, a proposed method of predicting changes in light output with ambient temperature from fluorescent street lighting luminaires. Also included is a brief review of the test technique used to get the data presented here, as well as a method which would enable anyone to predict changes in light output with ambient temperature from enclosed street lighting luminaires.

## Weather

A glance at any daily weather map issued by the United States Weather Bureau, will convince anyone that temperature is a function of location and time. Therefore, considering a fluorescent street lighting luminaire, what temperature range should we design for, and over what range can it be expected to operate, within the boundaries of the United States of America? An analysis of United States Weather data, taken from isotherm plots of the United States is shown in Table I.

TABLE I.

| | Approx. Temp. in F |
|---|---|
| Lowest isotherm shown | −60 |
| Lowest average annual minimum isotherm | −40 |
| Lowest average monthly isotherm for January | 0 |
| Highest average monthly isotherm for July | 90 |
| Highest isotherm shown | 120 |

More detailed information can be obtained from the references, but to show the average monthly temperature (for January, for instance, since it is the coldest month) variations within the eastern half of the United States is presented, Fig. 1. Keep in mind, also, that during the year the coldest temperatures occur in Montana and the hottest temperatures occur in Arizona.

For our particular application, we have selected for study an operating range of from −20 F to 90 F range. Our ballasts, however, are designed to start

A paper presented at the National Technical Conference of the Illuminating Engineering Society, September 14-17, 1953, New York, N. Y. AUTHORS: General Electric Co., Lighting and Rectifier Dept., Lynn, Mass.

Fig. 1.—Average Monthly Isotherms for January, within the United States.

lamps in temperatures down to between −20 F and −30 F. We feel that although extremes −60 F to +120 F are shown, the operating range selected will suffice for practically all fluorescent street lighting installations, because of the time of day they are operating.

Most of the data presented in this paper has been taken in the presence of a 2-mph wind, and is marked accordingly.

Rain or snow, wind velocity and direction, etc. do affect light output from these types of luminaires, but these factors were for definite reasons not investigated at this time. A testing program, however, is under way to ascertain their effect.

### Effect of Temperature on Light Output

Previous papers have shown that the light output of fluorescent lamps is dependent upon the bulb wall temperatures. That, in turn, is dependent primarily on the type of lamp, its current, and surrounding ambient temperature. Assuming one type of lamp and current, it is obvious that the surrounding ambient temperature can be greatly affected by the type of enclosing luminaire within which the lamp (or lamps) is operated. The purpose of this paper is to present data on the variation of bulb wall temperature and luminaire light output with the external ambient temperature of the luminaire.

Since many factors affect the light output of fluorescent lamps in street lighting luminaires, a test program was set up on which the many variables could be controlled. Over a range in ambient temperature of the luminaires, of from −20 F to 90 F, readings were taken of light output, bulb wall temperature, lamp current and primary voltage of the ballast. These results, on one type of luminaire, are shown in Fig. 2. For various primary voltages on the ballast, they show a consistent trend of lower lamp bulb wall temperatures as the luminaire ambient temperature is lowered to −15 F, and at the same time a rise in light output. Similar

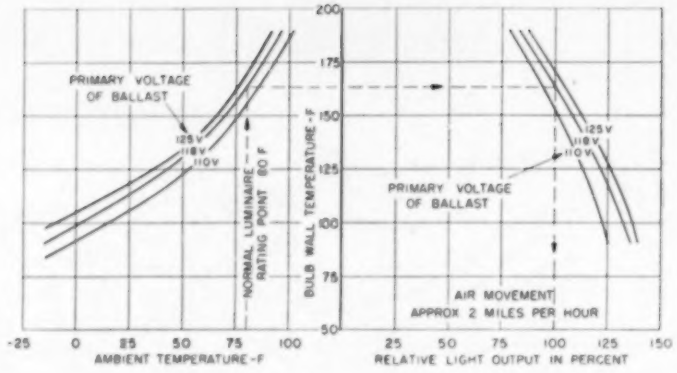
PRIMARY VOLTAGE OF BALLAST
125 V
118 V
110 V
NORMAL LUMINAIRE RATING POINT 80 F
BULB WALL TEMPERATURE - F
AMBIENT TEMPERATURE - F
PRIMARY VOLTAGE OF BALLAST
AIR MOVEMENT APPROX 2 MILES PER HOUR
RELATIVE LIGHT OUTPUT IN PERCENT

**Fig. 2.—Curves of light output as affected by bulb wall or ambient temperature, for a range of ballast primary voltages, for a street lighting luminaire having two reflector sections back-to-back, and mounting four 72T12 fluorescent lamps. Normal rating temperature of 80 F for photometric data of fluorescent luminaires shown correlated with 100 per cent relative light output.**

temperature trends, for other luminaire and lamp combinations, have been found, as shown in Fig. 3. Curves A, B and C (in Figs. 3 and 5) are for a luminaire of a single reflector type of construction (see Fig. 6), while curve D is for a luminaire having two reflector sections back-to-back (see Fig. 8). It should be noted that although curve D in Fig. 3 is for the same luminaire as the curve in Fig. 2, the slight difference between them is due to the primary ballast voltage being held constant in Fig. 2, while the lamp current was held constant in Fig. 3. The trend shown in Fig. 3 is for higher lamp wattages per luminaire to raise the curve, *e.g.*, to higher bulb wall temperatures for a given ambient temperature of the luminaire. In other words, the position of a curve along the vertical axis, and its shape, are functions of the rate at which the luminaire is generating and dissipating heat.

It was interesting to note that as the relative light output (in per cent of the maximum) of the same combinations was plotted against bulb wall temperature, they fell along the same curve. That curve also seemed to be similar to the one shown to exist for bare lamps. All points, bare lamp data[4] and luminaire-lamp data were, therefore, plotted together with the result shown in Fig. 4. It shows again that maximum light output from the lamps themselves, regardless of their ultimate environment, occurs when the bulb wall temperature is in the neighborhood of 100F. This is good news to the designer of fluorescent luminaires, but not much use to the ultimate user. Curves of relative light output *vs* ambient temperature of the luminaire would prove of more value to the ultimate user. For the same luminaire and lamp combinations mentioned previously, these curves are presented in Fig. 5. Since 80F is the ambient temperature for which the photometric data for the luminaire are given, these curves are shown having 100 per cent light output for this temperature.

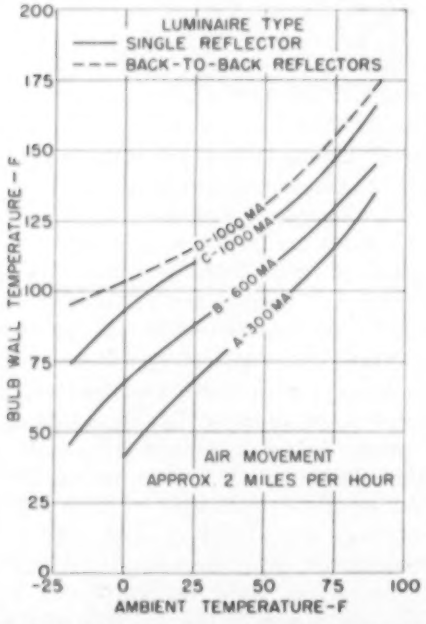


**Fig. 3.—Bulb wall temperature as affected by ambient temperature for different street lighting luminaire-lamp combinations. Curve A, one 96T8 lamp. Curve B, two 96T12 lamps. Curve C, two 96T12 lamps. Curve D, four 72T12 lamps.**

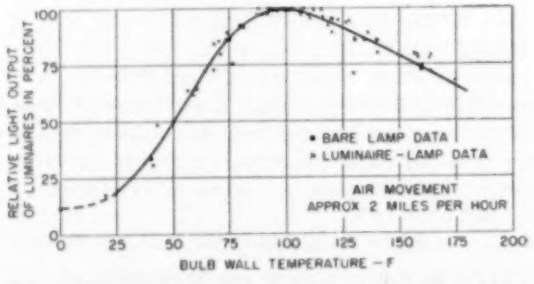
RELATIVE LIGHT OUTPUT OF LUMINAIRES IN PERCENT
• BARE LAMP DATA
× LUMINAIRE - LAMP DATA
AIR MOVEMENT
APPROX 2 MILES PER HOUR
BULB WALL TEMPERATURE - F

**Fig. 4. Light output of enclosed street lighting fluorescent luminaires as affected by bulb wall temperature. Composite curve obtained from lamps operating bare and inside various types of luminaires. Different lamp currents for the same luminaire also included.**

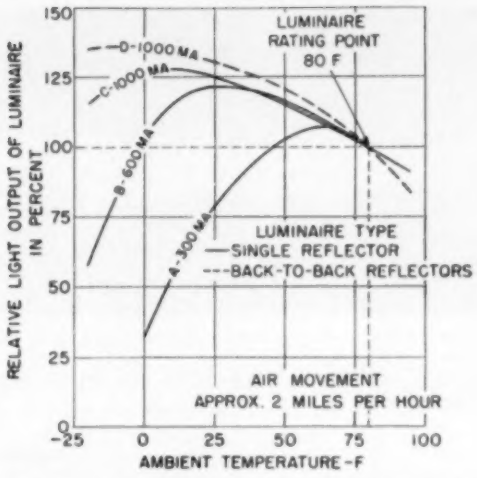


**Fig. 5.—Relative light output of enclosed Street Lighting Fluorescent Luminaires as affected by the ambient temperature for different luminaire-lamp combinations. Curve A, one 96T8 lamp. Curve B, two 96T12 lamps. Curve C, two 96T12 lamps. Curve D, four 72T12 lamps.**

This makes it possible for anyone to correct the photometric data, for any particular luminaire, to the ambient temperature in his locality at the moment. Here again, the trend of increasing output with increasing lamp wattage per luminaire, for a given ambient temperature, is shown; the maximum light output (occurring at approximately 100F bulb wall temperature) cresting at different ambients because of the different rates at which the luminaires are generating and dissipating heat.

In arriving at the curves shown in Fig. 2, information on bulb wall temperature, ambient temperature and light output of the luminaire was needed. It is not too difficult to measure temperatures accurately, but light measurements present difficulties to those unfamiliar with the art. However, with the ground work now well along, it is possible to predict light output from any enclosed fluorescent luminaire by taking certain temperature data.

One requisite is that the test room must be large enough to handle the luminaire and one in which the temperature can be changed over the selected temperature ranges. Curves similar to those shown in Fig. 3 are obtained, and these combined with the light output *vs* bulb wall temperature shown in Fig. 4, permit anyone to plot a curve of relative light output *vs* ambient temperature, shown in Fig. 5, for his particular luminaire. Various other researchers have shown the light output *vs* bulb wall temperature curve for bare lamps. This paper extends it (see Fig. 4) to lamps operating within enclosed fluorescent luminaires.

## Testing

Given a luminaire, representative of factory production in all respects, what equipment and test technique are needed to obtain these temperature data? A room of sufficient size, in which a fluorescent luminaire can be mounted, away from large objects, approximately 5 feet above the floor, and in its normal operating position. The room should be capable of covering readily the operating range of temperatures to be studied. Bulb wall temperature measurements are usually taken by specially constructed thermocouples and attached to the underside of the fluorescent lamp (see Fig. 7) approximately 12 inches in from the end (to minimize end effect of the lamp). Care must be taken that radiation effects upon the thermocouples are minimized and sufficient contact of the bead against the glass is maintained to assure the actual glass bulb wall temperature being obtained. With these precautions in mind, the test can proceed. Holding ballast primary voltage constant, readings are taken of both temperatures and lamp current, after stable operating conditions have been reached at a particular ambient temperature. Experience has shown that at most ambient temperatures, continuous operation for approximately three-quarters of

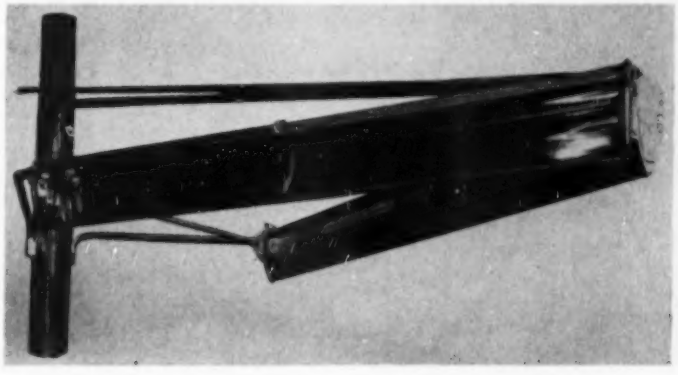

**Fig. 6.—Fluorescent luminaire, consisting of two single reflectors spread 30° between units. Individual reflector units can be operated either as single units or in pairs (as shown) with either one or two 96T8 or 96T12 fluorescent lamps.**

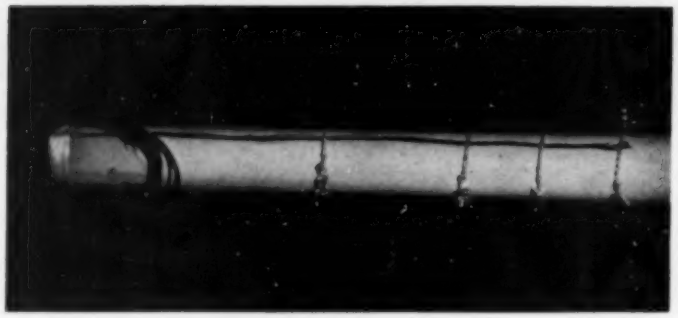

**Fig. 7.—Method of thermocouple attachment to bulb wall of fluorescent lamp. View shows thermocouple bead held against bulb by means of asbestos cord, and firmly secured at end of lamp by glass tape.**

an hour is sufficient to yield stable operation conditions.

For those desirous of taking their own light measurements in addition, the following comments are given. Since only one color of fluorescent lamp is used in a test, photo-voltaic cells corrected for the eye sensitivity curve are not necessary, but can be used if desired. For simplicity and reliability, a galvanometer (approximately 100 ohms resistance on all ranges) across the cell is recommended for reading the cell output. To eliminate stray light, install the cell within a box having a baffled opening for light to enter. For stable cell operation, the temperature within the cell box should be thermostatically controlled to approximately 90F to 100F. Depending upon light available from the luminaire and the expected performance, vary the number of cells or the distance to the luminaire to get the desired scale deflection on the galvanometer. Locate the cell box in approximate center of luminaire, and fasten the cell box and luminaire securely together. With the luminaire set up in the test environment, and with the lamps not operating, check (and adjust setup if necessary) for stray light from extraneous sources reaching the cell Tests have shown that with the setup described (shown in Fig. 8) and using reasonable precautions, results can be duplicated within ±2 to 3 per cent even with the equipment taken down and set up again in a new location.

## Summary

This paper has pointed out the sensitivity of fluorescent lamps to temperature, and shown that each luminaire reacts differently. It has indicated the need for a simple method of prediction, and, with the light output data shown in Fig. 4, presented a solution to the problem. Testing techniques and equipment necessary to obtain such information have been touched upon in sufficient detail to guide others interested in this kind of testing.

The authors acknowledge the help given by Mr. Kirk M. Reid and his associates at Nela Park.

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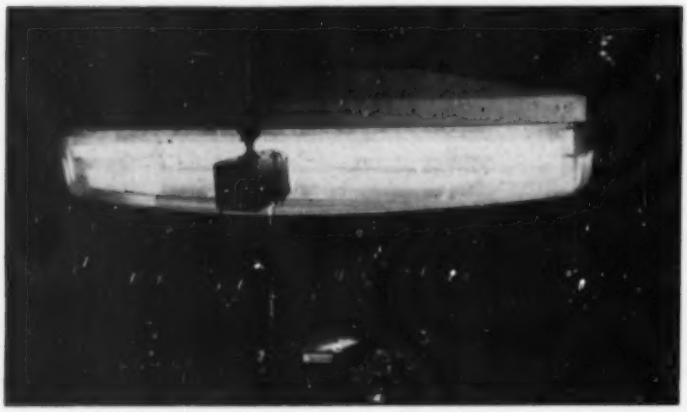

**Fig. 8.—Luminaire, having two back-to-back reflectors, on test in normal room ambient temperature. View shows cell box (center), rigidly mounted against luminaire, and the necessary instrumentation (bottom).**

## DISCUSSION

D. W. Rowten*: In my opinion this is one of the most practical papers presented for some time. The authors are to be congratulated on their evaluation of the problem and the test data reported.

The authors start out by listing ten factors that may influence the final results of an outdoor fluorescent lighting system. Unfortunately the paper only concerns itself with the effect of ambient temperature on light output with a two-mile-an-hour wind. While this is very important, we do not believe the data presented will permit an application engineer to adequately predict lighting results when some of the other factors are present, particularly the variable weather conditions. Are we convinced that the data justify the implied conclusion that the ideal lamp should be rated at 80F and that the maximum light output should be at zero or below when the average mean temperature when street lighting is required is around 50F?

It does not appear to be clear from Figs. 3 and 6 and the text, whether curves B and C are based on two lamps per reflector or two per double luminaire (*i.e.*, one per reflector) as shown in Fig. 6.

Since color-corrected photocells are easily available, why were they not used? It is possible that larger variations in temperature may change somewhat the color of the light emitted by fluorescent lamps.

Again I wish to thank the authors for this paper. It represents the type of information we need. I hope they will be encouraged to pursue this investigation further.

A. B. Winters**: I have reviewed the paper by Messrs. Bock and Franklin thoroughly and find it quite interesting. However, I think the information needs a lot of study before the I.E.S. standard practice can be reviewed with the possibility of adding sufficient information to guide the ultimate user in the application of fluorescent street lighting. To collect data in the laboratory under control conditions with accurate instruments is one thing but to double-check these data in the field would be quite difficult.

I would like to direct a question to the authors as to how these data can be applied to the I.E.S. recommended practice. Tables of recommended footcandle levels are based on maintained or inservice values. Since the user is the most concerned about these values, I would like to know whether he should base his calculations on January weather or July weather for any particular locality. In their discussion of testing, special thermocouples are mentioned; is it possible that some description of this thermocouple could be had? Also they stated that the thermocouple is placed on the under side of the lamp. Is it not true that the bottom side of the lamp is cooler than the top in which case the side of the lamp would give more of an average condition?

Would it be possible for them to explain more about the radiation effects mentioned? In the first paragraph on page 114 it is mentioned that temperature of the cell box should be maintained at approximately 90F to 100F. How it is possible to maintain these temperatures, especially on a cold day of near zero weather, out on the roadway?

Again I would like to congratulate the authors on this presentation but in the back of my mind I am wondering if the information would be of little use to the ultimate user unless some standards for its use are established by the I.E.S.

*Westinghouse Electric Corp., Lighting Division, Cleveland, Ohio.
**Revere Electric Mfg. Co., Chicago, Ill.

D. A. Toenjes*: The authors of this paper have made information available that will be valuable to any present or prospective user of outdoor fluorescent lighting equipment. Knowing the temperatures that will be encountered, he can, with these data, predict performance within a reasonable range and be guided in application and choice of equipment.

The authors have studied an operating range from —20F to +90F. Although this is not a range as broad as the extremes of temperature encountered in this country, they suggest it as being a practical one for a study of effect upon light output, since such a range will include most night-hour temperatures. However, the authors have also mentioned starting temperatures down to —30F. If this were the temperature at the early-evening starting time, we expect that the lamp would continue operating at the somewhat lower temperatures during the night.

In several places the authors have mentioned "ambient temperature of the luminaire." The wording here may be misleading. We assume that they mean to describe the ambient temperature of the air surrounding the luminaires, rather than the result of any thermocouple measurement upon the face of the luminaire itself. Is this correct?

In the section entitled "Testing," the authors have described some of the techniques used in taking light measurements. They have not mentioned whether the galvanometers and other instruments were connected so that they could be located outside the cold room. This would prevent the changing ambient temperatures from causing condensation inside the instruments. In our own tests, we found this especially important in the case of the sensitive deflection pyrometer connected to the bulb-wall thermocouples. Did the authors place some of their indicating instruments actually inside the cold room, and if so, did they have any trouble with condensation?

As an increasing number of fluorescent outdoor-lighting luminaires come onto the market, there will no doubt be differences in luminaire size and method of construction. In various luminaires using the same numbers and types of lamps, do the authors feel that differences in luminaire volume and in tightness of enclosure will result in differences between the characteristic light-vs-temperature curves?

Although the authors have mentioned factors such as rain and snowfall, they have not mentioned any possible effect of differences in humidity of the air. Do they feel that this effect would be minor in comparison with the others? We shall be interested in learning the effects of other factors, such as rain, snow, and wind velocity, that the authors have mentioned as being under present study.

J. E. Bock and J. S. Franklin**: The three discussors have shown their knowledge of the subject by the depth of the questions raised. In the comments that follow, all questions on related subjects have been grouped together.

*Temperature.* We have found that of all the factors affecting light output, the ambient temperature and wind velocity of the air surrounding the luminaire are of major importance. For the purpose of the study we have confined our indoor laboratory tests to variations in the air temperature under very low wind velocities. To do otherwise would involve the use of wind tunnels or outdoor measurements under uncontrollable conditions. Both present extreme difficulties as our outdoor tests to date have indicated.

*Application Engineering Dept., Lamp Division, General Electric Co., Cleveland, Ohio.
**Authors.

Mr. Toenjes is correct in assuming that we mean the ambient temperature of the air surrounding the luminaire.

In calculating footcandle levels based upon maintained values we are using the average yearly mean temperature for a particular locality.

We did not wish to imply that the ideal lamp should be rated at 80F and that zero is the ideal temperature for maximum light output from a fluorescent streetlighting luminaire since we must measure light output at the rating temperature. To rate fluorescent lamps at a temperature greatly different from 80F would present problems in lamp photometry. As to the luminaires, the temperature at which maximum light output occurs is a function of the many design variables mentioned in the beginning of the paper. We, therefore, would expect each luminaire to exhibit a different light-vs-temperature characteristic.

In determining our choice of photovoltaic cells, we have overlooked whatever change in color might occur as the ambient temperature of the air surrounding the luminaire was varied. Even though its effect may be small, we will use color-corrected cells in the future.

In all our tests, all instruments were outside the variable temperature room at all times. The air in the cell box was heated from resistance units laid along the bottom of the box.

*Thermocouples.* Standard Copper-Copnic thermocouples (*30AWG) were used with the exception that the wires shall not be twisted at the bead but brought away immediately in the form of a "V." A bow or hump is placed in the couple immediately back of the junction point to produce sufficient tension to hold the junction firmly against the glass bulb. The junction will absorb some light and heat and this tends to give a high reading. Keeping both the junction and the bow small makes the possible error small.

The under side of the lamp is chosen because the coolest part of the lamp is the best barometer of lamp performance.

*Miscellaneous.* Curves B and C in Fig. 3 are for two lamps per reflector, the solid line representing a single reflector.

We are pleased by the interest shown in this paper and wish to thank Mr. Rowten, Mr. Winters and Mr. Toenjes for their helpful comments on our work.

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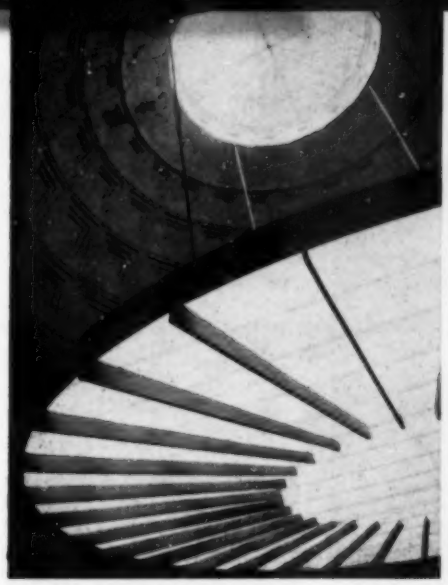
## High-Level Standard-Color Lighting For Fur Inspection

**A lighting unit for the inspection of live mink and other fur animals, and also for inspecting and judging pelts, has been designed by D. L. Anderson of Salt Lake City, Utah, through the cooperation of the Western International Fur Animal Show and the Utah Fur Breeders Association. The requirements for this application are a high level of illumination for seeing deep into the fur and a color simulating that of the northern sky on an overcast November day — about 6000K.**

**Two 500-watt 120-volt #2 photoflood lamps operated at 100 volts, using a step-down transformer, are mounted back-to-back (in right side of fixture in photo as shown). Reflector surfaces are painted with a specially mixed blue-white paint to provide the north-sky color. Illumination on a judging table, 36 to 40 inches below the unit, is 130 footcandles. Lamp life, on 100-volt operation, is about 30 hours.**

**Single units — 48 by 36 inches by 27 inches high — can be used on individual farms and ranches. For show purposes they can be banked together, each producer furnishing one unit. Fixture design allows for ventilation, with openings below the lamps and at the apex of the reflector. Tests indicate no appreciable rise in temperature on the working plane.**

**Photo and data supplied by Data Sheet Chairman of the I.E.S. Utah Chapter, George B. Earl, Utah Power and Light Co.**



**The "spider web" at top of photo at left is the original skylight in the dome. About one-half of the remaining floodlights are located directly below it. In addition to the perforated acoustical baffles beneath the luminaire, the entire upper surface is covered with 4 inches of sound absorbing material.**

# Lighting the Interior of the M. I. T. Engineering Library Dome

THE SECTION under the dome of Central Library at Massachusetts Institute of Technology is used as the Engineering Library, lighted by a 16-ton suspended lighting unit believed to be the largest ever installed.

In this space the lighting and acoustics were poor and many ideas were furnished for their correction. Among other suggestions, some felt that the 30,000 watts of floodlighting at the eye of the dome would be made effective at reading levels if the dome surfaces were painted with high reflectance paint.

The solution proposed by Professors L. B. Anderson and H. L. Beckwith included five objectives: (1) to keep the dome, which to many symbolizes the Institute externally, clearly defined as a dome when one is inside the building; (2) to avoid means which would require frequent painting of the dome, because of the great amount of expensive scaffolding and materials needed; (3) to maintain a level of illumination highly satisfactory at table top reading levels; (4) to substantially reduce the reverberation of the room; and, (5) to compress the great size of the original space to a smaller scale, more friendly and less distracting.

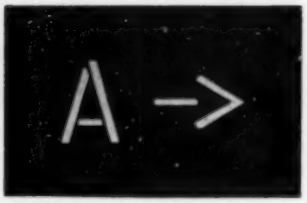
Pictures and data supplied by The F. W. Wakefield Brass Co., Vermilion, Ohio.

### Method

A gigantic luminous-indirect, fluorescent lighted, "Chandeluminaire" which includes 28 light metal, hollow, acoustical baffles, 16 feet long and perforated for sound absorption by materials within, is suspended 14 ft 2 inches above the floor. The suspension is by four members $2\frac{3}{8}$ inches in diameter O. D. seamless steel tubing, hung from a framework of steel attached at twelve points to the structural concrete dome. The tubes provide the wiring channels to the luminaire hanging 51 feet below the skylight of the dome. Diffusers are of corrugated acrylic plastic.

### Power — Lighting

The total kilowatt load for 92 72-inch and 144 48-inch T12 fluorescent lamps is about 14 kilowatts. Less power is required than originally for the giant unit and the flood lights left in the dome after remodelling. After three months in service the "Chandeluminaire" delivers 75 footcandles at desk surfaces. There is considerable contrast between the luminaire lower surface and dark floor and furniture. The installation of the lighting, however, was considered the first step in a renovation which will replace the dark floor and furniture with lighter shades, to bring brightness comparisons throughout the area much closer together.




INSTALLATION AT INDIANAPOLIS MUNICIPAL AIRPORT, INDIANAPOLIS, INDIANA.

# Lighting an Airport Taxiway Sign

**LIGHTING OBJECTIVE:** To illuminate taxiway directional signs at night to help guide pilots around large air terminals.

**GENERAL INFORMATION:** The face of the sign shown is a 12" x 12" removable panel made of orange plastic (Rohm & Haas No. 2068) with 50 per cent reflectance and 25 per cent diffuse transmittance. The exterior, except the letters which are 10¾ inches high with a ¾-inch stroke, is enamelled black (reflectance 3 per cent). The panel is free to slide in and out of the track. The housing is approximately 15 inches high and 8 inches from face to face.

**INSTALLATION:** Figure 2 shows the lighting arrangement. One 25-watt 120-volt lamp is employed in each section. The resultant brightness at night is 35 footlamberts. This unit was designed to be legible at 500 feet when the meteorological visibility is ¼ mile.

Signs of this design are now manufactured by the Crouse-Hinds Company, Syracuse, New York.

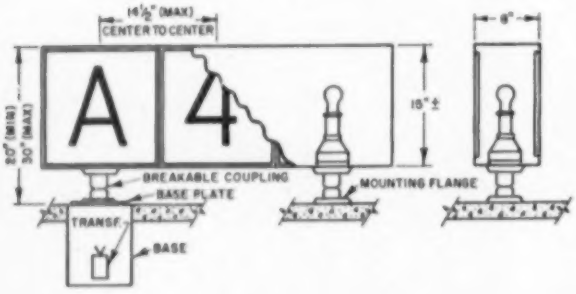
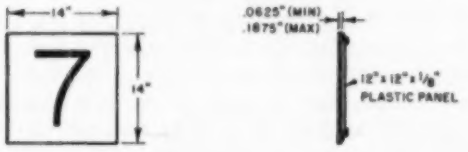



Figure 2. (left) Typical three-panel sign.

Figure 3. (below) Typical face plate with plastic panel.




**Designed by engineers of the Lighting Branch, Technical Development and Evaluation Center, Civil Aeronautics Administration, Indianapolis, Indiana.**

**Lighting data submitted by Arthur T. Tiedemann, C.A.A., Indianapolis as one solution to a lighting problem and to aid in the design of similar installations.**

**Published by the Committee on Publications of the Illuminating Engineering Society, 1860 Broadway, New York 23, N. Y.**

Series XIX 2-54

A.I.A. File No. 31-J

# TELECAST

## LIGHTING NEWS OF CURRENT INTEREST

### President Inspects 1954 Conference Site

Plans for the 1954 National Technical Conference were underway as soon as the hotel—the Chalfonte-Haddon Hall—was chosen. Here I.E.S. President A. H. Manwaring and Conference Executive Committee Chairman A. S. Turner are seated in a boardwalk chair discussing arrangements with the hotel's Sales Manager Ellsworth Sooy, to insure the most convenient and pleasant facilities for I.E.S. Conference delegates.

### A.I.E.E. Papers Present Study of Lighting Maintenance

The behavior of the "elusive lumen" was reviewed at two sessions of the Winter Meeting of the American Institute of Electrical Engineers, held at the Hotel Statler, January 18-22. Seven reports on this subject were presented during two sessions on January 19, with well-known I.E.S. members discussing how more and better light can be made available economically. The morning session, entitled "Behavior of the Elusive Lumen," featured the following three papers:

"Economics of Lamp Operation and Replacement Under Normal and Abnormal Conditions," by E. A. Linsday, General Electric Co., Cleveland; "Industrial Luminaires Designed for Cleaner, Better Operation," by Eric Church, Benjamin Electric Mfg. Co., Des Plaines, Ill.; "Commercial Luminaires Designed for Longer Life, Easier Maintenance," by Dana Rowten, Westinghouse Electric Corp., Cleveland.

In the afternoon session, entitled "Controlling the Elusive Lumen," lighting maintenance papers presented were:

"Mass-Production Methods Applied to Lamp Replacements and Fixture Cleaning," by Fred Vorlander, Vorlander Lighting, Boston; "The Practical, Profitable Maintenance Program at Sperry," by James Kimball, Sperry Gyroscope Co., Long Island City, N. Y.; "John Hancock Insurance Co.'s Program to Insure Good Lighting at Low Cost," by T. C. Sargent, Sylvania Electric Products, Inc., Salem, Mass.; "Making a Business of Lighting Maintenance," by A. Marmon, Broadway Maintenance Co., New York, N. Y.

A discussion forum on how simplified maintenance keeps the elusive lumen at work followed the presentation.

### Plant Maintenance Conference To Be Held with West Coast Show

Concurrent with the West's first Plant Maintenance Show scheduled to be held in the Pan Pacific Auditorium, Los Angeles, July 13-15, will be a Plant Maintenance Conference. The Conference will be under the direction of L. C. Morrow, consulting editor of *Factory Management and Maintenance* magazine.

In the July show, exhibits and discussions will cover sanitation, replacement of parts, preservation of facilities and equipment, safety devices and measures, painting, polishing, waxing, industrial design, and supplies of every sort which do not actually become a part of the finished product.

The Plant Maintenance Show is aimed at industrial efficiency — in the broadest sense — for every type of manufacturing operation, large or small. Products, equipment and supplies—and methods—that have an effect on lowering production costs will all be included in the show.

### Lighting Design Course Planned For U. of C. Curriculum

A Spring semester course on Lighting Design is being offered by the Engineering Department of the University of California, with two-hour weekly classes from February 15 to June 4. Two units of credit will be given to regularly enrolled students. The course, under the direction of D. M. Finch, will include: requirements for good lighting, glare, visibility measurements, lighting calculation methods, lighting system design and electrical wiring for lighting.

### British I.E.S. Plans Conference in May

American visitors to England next summer have been cordially invited to attend the annual summer meeting of the British I.E.S. Their conference is scheduled for May 18 through May 21, 1954, at Southport, England.

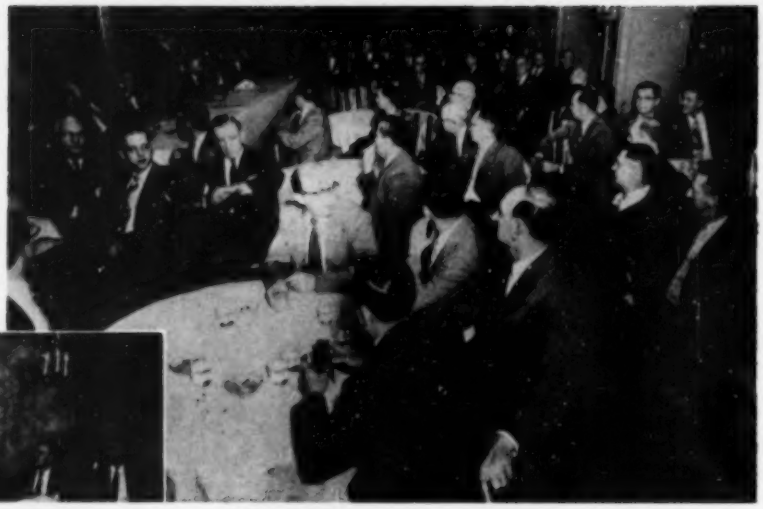
Advance notices of their meeting indicate the following program:

Lamps and Their Uses, by Dr. J. H. Aldington (Managing Director of Siemens Electric Lamps & Supplies, Ltd.).

Street Lighting of a Large London Suburb, by A. T. Durbridge (Eastern Electricity Board).

The Decorative Approach to Commercial Lighting, by Andre Claude (Claude, Paz & Silva, Paris).

## Here and There With I.E.S. Members



A total attendance of 166 — including many rural agents — attested to the success of the meeting of the Eastern Pennsylvania Section featuring Farm Lighting. Guest speaker was Joe Ditchman, farm lighting specialist of General Electric Co., whose topic was "Light Energy for Plants and Animals." At the head table (shown in inset) are: Oscar Lange, Chairman of the I.E.S. Farm Lighting Committee; Ford Gochenaur, Section Secretary; Joseph Ditchman, guest speaker; Paul Kinsey, Section Vice-Chairman; Calvin Staudt, Local Representative from Pottsville, Pa.; and A. J. Tobias, farm supervisor for Pennsylvania Power and Light. Place: the Necho Allen Hotel in Pottsville.

(Left) Arizona Chapter Chairman, Stanley L. Burnham, at left, discusses the agenda with guest speaker Matt A. Cabot, Day-Brite Lighting Inc., just prior to the Chapter's January 8 meeting. Mr. Cabot spoke on School Lighting.

Dinner meetings of the I.E.S. Rochester Section are taken seriously (below left) and matters of illuminating engineering are of prime interest. (Note the "suitcase" publications display.) Below, in a lighter mood, Rochester members add up scores with Western New York Section members after their annual golf tournament. Photos by Carl Pollock, Publicity Chairman of the Section.

Home Lighting, by A. H. Young (Troughton & Young, Ltd.).

Lighting for Plant Growth, by A. E. Canham (Electrical Research Association).

A series of papers on the economics of different types of industrial lighting installations including hot cathode, cold cathode, high bay mercury and blended light installations. (To be given by consulting engineers and factory engineers.)

The program will also include a display of new lighting equipment, and a number of educational and technical visits.

Full details of the meeting will be available shortly and may be obtained from the I.E.S. Secretary, 32 Victoria Street, London, S.W. 1.

## Basic Course in Illumination Presented by Pittsburgh Groups

A study course in fundamentals of illumination, consisting of eight two-hour meetings, is being sponsored by the Pittsburgh Section of I.E.S. with the Electric League of Western Pennsylvania. The classes met weekly, beginning January 18, and covered a broad field of basic illuminating engineering including:

Light Is What You Make It
Light and Vision
Illumination Terminology
Quantity Requirements of Good Illumination
Quality Requirements of Good Illumination
Importance of Color Illumination
Incandescent, Electric Discharge and Fluorescent Lamps
Principles of Light Control
Systems of Light Control
Calculation of Interior Illumination
Office and School Lighting
Store Lighting
Industrial Lighting and Flood Lighting

Classes were held in the Conference Room of the West Penn Power Co. Registration fee was $5.00 for the entire course.

## E.E.I. Organizes New Inter-Industry Coordinating Group

Formation of a new group for the coordination of electrical industry sales and promotional programs, to be known as the Conference Group on Coordination of Electrical Industry Sales and Promotional Programs, was announced by member organizations of Edison Electric Institute.

According to E.E.I.'s stated plans the program is tailored to fill a long existing gap in coordinating the overall sales efforts of the several national electrical industry associations.

Members presently include Edison Electric Institute, International Association of Electrical Leagues, National Association of Electrical Distributors, National Electrical Contractors Association, National Electrical Manufacturers Association, and National Appliance and Radio-Television Dealers Association.

J. R. Hartman, Vice-President, Cincinnati Gas and Electric Co., and Temporary Chairman of the Conference Group, said: "The main purpose of this group will be to serve as the medium to keep the various associations of the electrical industry advised on the promotional and sales efforts of the others, and to make an effort to coordinate these activities for the achievement of maximum effectiveness."

Thus far, the Conference Group has prepared an inventory of sales and promotional programs of all the associations

# LIGHTING CALENDAR

## Society Events

**April 8-9, 1954**—Southern Regional Conference, Roosevelt Hotel, New Orleans, La.

**April 10, 1954**—Meeting of the I.E.S. Council, Roosevelt Hotel, New Orleans, La.

**April 11-13, 1954** — Southwestern Regional Conference, Rice Hotel, Houston, Texas.

**April 15-16, 1954**—Inter-Mountain Regional Conference, Denver, Colo.

**April 19-20, 1954**—South Pacific Coast Regional Conference, Museum of Art, San Francisco, Calif.

**April 22-23, 1954** — Pacific Northwest Regional Conference, Benjamin Franklin Hotel, Seattle, Wash.

**April 29-30, 1954**—Canadian Regional Conference, King Edward Hotel, Toronto, Ont.

**May 3-4, 1954** — Great Lakes Regional Conference, Sheraton-Cadillac Hotel, Detroit, Mich.

**May 17 or 18, 1954** — Northeastern Regional Conference, Hartford, Conn.

**June 10, 1954**—Meeting of the I.E.S. Council, New York, N. Y.

**June 17-19, 1954**—Midwestern Regional Conference, Jefferson Hotel, St. Louis, Mo.

**September 13-17, 1954**—Illuminating Engineering Society, National Technical Conference, Chalfonte-Haddon Hall, Atlantic City, N. J.

## Industry Events

**February 22-25, 1954**—Third Annual Industrial Ventilation Conference, Kellogg Center, Michigan State College, East Lansing, Mich.

**March 8-11, 1954**—National Electrical Manufacturers Association, Edgewater Beach Hotel, Chicago, Ill.

**March 9-12, 1954** — American Management Association, General Management Conference, Fairmount Hotel, San Francisco, Calif.

**March 10-12, 1954** — American Society of Mechanical Engineers, International Meeting, Del Prado Hotel, Mexico, D. F.

**March 18-19, 1954** — American Trade Association Executives, Spring Meeting, Sheraton-Carlton Hotel, Washington, D. C.

**April 1-3, 1954** — Electrical Industry Show, Shrine Exposition Hall, Los Angeles, Calif.

**April 5-8, 1954**—Edison Electric Institute Sales Conference, Edgewater Beach Hotel, Chicago, Ill.

**May 3-7, 1954** — Society of Motion Picture and Television Engineers, Semi-Annual Convention, Hotel Statler, Washington, D. C.

**May 13-14, 1954** — Public Utilities Advertising Association, National Convention, Hotel Statler, Boston, Mass.

**May 17-20, 1954** — Basic Materials Exposition, International Amphitheatre, Chicago, Ill.

**May 19-21, 1954** — Pacific Coast Electrical Association, Inc., Hotel Del Coronado, Coronado, Calif.

**June 6-11, 1954** — National Association of Electrical Distributors, 46th Annual Convention, Atlantic City, N. J.

**June 7, 1954, Week of** — Society of the Plastics Industry, Sixth National Exposition, Cleveland, Ohio.

**June 20-24, 1954** — The American Society of Mechanical Engineers, Semi-Annual Meeting, William Penn Hotel, Pittsburgh, Pa.

**June 21-25, 1954** — American Institute of Electrical Engineers, Summer General Meeting, Los Angeles, Calif.

**September 8-10, 1954**—The American Society of Mechanical Engineers, Fall Meeting, Schroeder Hotel, Milwaukee, Wis.

**September 22-24, 1954**—Canadian Electrical Manufacturers Association, General Brock Hotel, Niagara Falls, Ont., Canada.

**September 29 - October 2, 1954** — International Association of Electrical Leagues, Bellevue Stratford Hotel, Philadelphia, Pa.

**October 4-7, 1954** — National Association of Electrical Distributors, Pacific Zone Convention, Mark Hopkins Hotel, San Francisco, Calif.

**October 11-15, 1954**—American Institute of Electrical Engineers, Fall General Meeting, Chicago, Ill.

**October 17-22, 1954**—Society of Motion Picture and Television Engineers, Semi-annual Convention, Los Angeles Ambassador, Los Angeles, Calif.

**October 18-22, 1954**—42nd National Safety Congress & Exposition of the National Safety Council, Chicago, Ill.

**October 24-27, 1954** — Board of Governors, National Association of Electrical Distributors, Hershey Hotel, Hershey, Pa.

**November 8-11, 1954** — National Electrical Manufacturers Association, Haddon Hall Hotel, Atlantic City, N. J.

**November 15-17, 1954** — 41st National Foreign Trade Convention, Waldorf-Astoria Hotel, New York, N. Y.

**November 15-17, 1954** — American Standards Association, 5th National Conference on Standards and 36th Annual Meeting, Hotel Roosevelt, New York, N. Y.

**November 28 - December 3, 1954** — The American Society of Mechanical Engineers, Annual Meeting, Statler Hotel, New York, N. Y.

## I.E.S. Regional Conferences, 1954

| | | |
|---|---|---|
| Southern | Roosevelt Hotel<br>New Orleans | April 8-9 |
| Southwestern | Rice Hotel<br>Houston | April 11-13 |
| Inter-Mountain | Denver | April 15-16 |
| South Pacific Coast | Museum of Art<br>San Francisco | April 19-20 |
| Pacific Northwest | Benjamin Franklin Hotel<br>Seattle | April 22-23 |
| Canadian | King Edward Hotel<br>Toronto | April 28-30 |
| Great Lakes | Sheraton-Cadillac Hotel<br>Detroit | May 3-4 |
| Northeastern | Hartford | Week of May 17<br>(one day) |
| Midwestern | Jefferson Hotel<br>St. Louis | June 17-19 |

represented on the Conference Group (this inventory is being distributed by the associations to their interested members), and has recommended to its constituent associations that "Electrical Modernization" should be adopted as the basic idea around which as many as is practical of the electrical industry's sales and promotional activities should be organized. Individual associations may interpret this idea to their specific needs.

"The members of the Conference Group believe," Mr. Hartman said, "that, if the electrical industry is to maintain its high level of sales in the competitive era ahead, it must coordinate its sales effort.

"For instance, at least 1,500,000 kitchens in American dwellings are being modernized annually — not to mention a million being installed in new houses. In fact, the replacement aspect in all electrical fields has been seriously overlooked.

"Industry can substantially increase its productivity through the use of modern electrical equipment, both for industrial drives and modern lighting. Automation can be brought about primarily through the use of more industrial electrical equipment. Electronics offer great possibilities for still further increasing our production per man hour."

In summary, Mr. Hartman concluded that the program of the Conference Group seeks to attain the common objectives of the utility, manufacturer, the distributor, the dealer and contractor through coordinated advertising and promotional campaigns.

## N. Y. Section, A.I.E.E. Sponsors Classroom Lighting Lectures

A series of six lectures on "What Do We Really Know About Classroom Lighting" is being sponsored by the Illumination Division of the New York Section of the American Institute of Electrical Engineers. The speakers, all prominent I.E.S. members, are: Dr. Domina Eberle Spencer, University of Connecticut; Henry L. Logan, The Holophane Co.; Carl Allen, General Electric Co.; Willard Allphin, Sylvania Electric Products, Inc., and C. L. Crouch, I.E.S. Technical Director. Weekly classes began January 13.

Among the subjects discussed were the proper limits on quality of illumination, the basis for brightness toleration and limitations, school lighting in other countries and progress made in the past decade.

Classes are being held at the General Electric Building auditorium.

## Dow Memorial Prize Contest Sponsored by British I.E.S.

A competition to encourage collaboration between students of illuminating engineering and those in other fields where applied lighting plays an important part is being sponsored by the British I.E.S. The competition is a memorial to John Stewart Dow, honorary secretary and past president of the Society, who died in 1948.

The entries will be judged by a panel appointed by the I.E.S., in cooperation with the Royal Institute of British Architects and the Institution of Electrical Engineers. The winning entry will receive a total cash award of £75. Subject for the 1954 competition is the layout, lighting, decoration and furnishing of a dining room and cocktail bar in a city hotel.

## Lighting Show Presented At N.A.H.B. Convention

A presentation of home lighting was made this year for the first time on the main program of the National Association of Home Builders Annual Convention, on January 18 at the Conrad Hilton Hotel, Chicago. A dramatic fifty-minute presentation entitled "The Builders Jubilee with Light" with a cast of 16 professional actors was sponsored by the Electrical Industry Lighting Committee. Staging was done by Theatre for Industry, an organization which has produced many such industrial presentations.

The show served a dual purpose in pointing out the value of good lighting as a selling feature in today's homes and as a part of the celebration of Light's Diamond Jubilee.

## Changes Sought in Engineering Codes

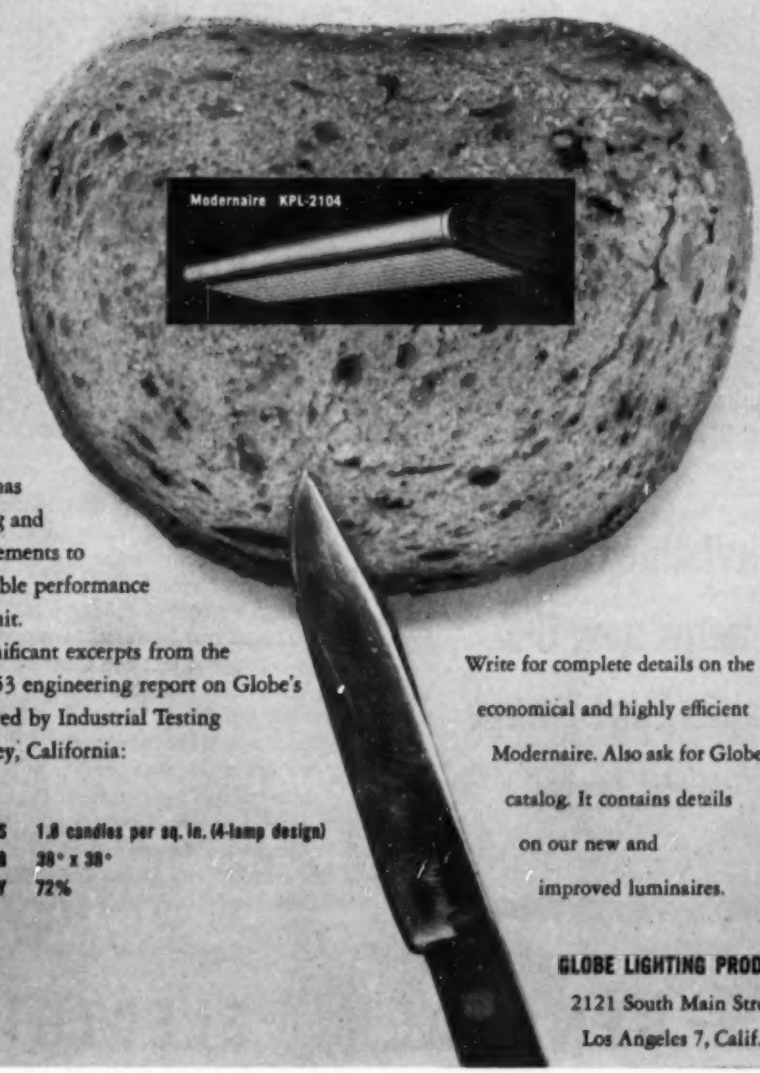
Prohibitions against competitive bidding for engineering services should be removed from professional codes of ethics, *Engineering News-Record*, McGraw-Hill publication, asserts editorially. They feel that illustrating the fallacy of the present restrictions is the fact that certain governmental units are subject to laws that require taking bids for contractural services. Engineers responding, they point out, now are liable to the stigma of unethical action. Changes in professional society codes should be made to correct this contradictory and unsatisfactory situation, the magazine maintains.

Recognition of bidding as a legitimate method of doing business would not mean capitulation to the unsound idea that price is the only — or even the most important — consideration in engaging engineering services; it would mean only that for a definite prohibition on ethical grounds would be substituted a guide for business procedure compounded of realism and a concern for the best interest of client and engineer alike, the magazine states.

The present procedure, which is accepted to accord with the code provision

(*Continued on page* 11A)

# LOOK WHAT GLOBE HAS DONE WITH




In basic design, Globe's Modernaire is as standard as bread-and-butter. However, Globe has added engineering and construction refinements to achieve a remarkable performance for this type of unit.
Look at these significant excerpts from the December 23, 1953 engineering report on Globe's KPL-2104, prepared by Industrial Testing Engineers, Berkeley, California:

| | |
|---|---|
| MAXIMUM BRIGHTNESS | 1.8 candles per sq. in. (4-lamp design) |
| SHIELDING | 38° x 38° |
| EFFICIENCY | 72% |

Write for complete details on the economical and highly efficient Modernaire. Also ask for Globe's 1954 catalog. It contains details on our new and improved luminaires.

**GLOBE LIGHTING PRODUCTS INC.**
2121 South Main Street
Los Angeles 7, Calif.

YOU EXPECT THE BEST VALUE FROM G-E FLUORESCENT LAMPS

## Invisible coating helps new G-E Rapid Start Lamps light faster

THE film of water that condenses on a fluorescent lamp in wet weather is so thin the lamp hardly feels damp. Still, it can connect the ends of the lamp and set up a miniature short circuit. It doesn't injure the lamp. Just steals enough current so the lamp is slow in lighting.

There's one fluorescent lamp, though, that doesn't get sluggish in moist air: the General Electric Rapid Start Lamp.

It has an invisible coating of General Electric silicone, called Dri-Film*. The photo shows what it does to water on the lamp. Makes it stand up in separate drops. In between are dry areas that break the electrical contact. The short circuit doesn't get started. The lamp does.

G-E Dri-Film* doesn't rub off. It's an example of why you expect the best value from G-E fluorescent lamps. For free booklet, "Facts About Rapid Start", write to General Electric, Dept. 166-IE-2, Nela Park, Cleveland 12, Ohio.

*REG. U. S. PAT. OFF.

*You can put your confidence in—*

**GENERAL ELECTRIC**

## I.E.S. National Technical Conferences

September 13-17, 1954 — Chalfonte-Haddon Hall, Atlantic City

September 12-16, 1955 — Statler Hotel, Cleveland

September 16-21, 1956 — Statler Hotel, Boston.

(*Continued from page* 8A)

prohibiting bidding, is for the prospective buyer to interview a number of invited engineers personally, receive their proposals and weigh their qualifications. In contrast to this relatively confidential procedure, the tendering of sealed bids to be opened and compared is frowned upon, the magazine points out.

Most governmental units throughout the country, however, are subject to laws that require taking bids for contractural services, thereby requiring action in direct violation of the code provision. Furthermore, when they advertise they invariably receive bids from engineers — who do know of the unethical stigma, but feel either that it is unjust or not serious enough to justify their turning down a job opportunity to avoid it.

The solution would be to sanction the submission of competitive proposals for engineering engagements under conditions that would minimize the possibility of an award being made on the basis of price alone. Thus the rules could specify that proposals could be made in writing to be publicly opened and read on a given date, and that each proposal must be accompanied by an outline of the engineer's qualifications, a detailed statement of the services that he intends to render and the amount or percentage of his fee, the magazine says.

"Such a procedure would require public officials to operate entirely in the open, thus affording the engineer protection against favoritism, which he sometimes now lacks. At the same time it would protect the public official from political pressure and from having to award a contract to an obviously unqualified engineer just because he submitted the lowest bid. With all of the qualifications and proposals made public, and with the schedule of minimum fees established by the profession as a guide, the public official could award the contract to the lowest qualified bidder, which is his objective, no matter what procedure is followed. So long as qualifications are made paramount, price remains in the secondary position where the present code provision seeks to keep it," the magazine says.

"The truth of the matter is that the attempt to prohibit competitive bidding on a price basis on ethical grounds is self-defeating and therefore unworkable. Not only does it invite men of high moral character to circumvent this provision of the code if they are to stay in business, but it offers no effective bar to keep unqualified men from securing the jobs," the magazine states.

## ABOUT PEOPLE

The 1953 Edison Medal, one of engineering's top awards, was presented to **John Findley Peters**, engineering consultant to Westinghouse Electric Corp., January 18 at the opening general session of the winter meeting of the American Institute of Electrical Engineers, at the Hotel Statler, New York City. Mr. Peters was honored for "his contributions to the fundamentals of transformer design, his invention of the Klydonograph, his contributions to military computers and for his sympathetic understanding in the training of young engineers." The Klydonograph is a device for recording surges on power transmission systems.

**Richard F. Townsend**, formerly commercial engineer for Westinghouse Electric Corp., in Bloomfield, has been appointed regional engineer for that company's Lamp Division in the New England region, effective February 1. He succeeds **Horace R. Finney** who, following a three-year tenure, was named manager of the firm's Sterilamp-Odor-out sales. Mr. Townsend will make his headquarters at the regional office in Belmont, Mass.

**Arthur M. Willman**, who retired recently after 27 years with the General Electric Co., in New York City, has joined Edward Bostonian, Inc., 30 Church St., New York, a District Sales Office for the Electro Silv-A-King Corp. Mr. Willman's association with the lighting industry goes back to the old Cooper Hewitt Electric Co., later G. E. Vapor Lamp Co., where he pioneered in the use of mercury vapor lamp sources.

Northern Electric Company, Montreal, has announced the appointment of **F. P. Labey** as Manager of the Wiring Materials Department of the General Sales Division, and of **A. G. V. Smith** as Manager of the Illumination Department of General Sales.

**Arthur A. Eastman**, physicist in lighting research at the Nela Park laboratories of General Electric Co., was formally initiated into Sigma Xi, honorary scientific research society of America, January 21, at the University of Kansas, Lawrence, Kan.

**Darell Boyd Harmon, Jr. and C. A. Winkelhake** have been added to the staff of Darell Boyd Harmon and Associates, Consulting Educationists, Austin, Texas. Mr. Winkelhake will occupy the position of Research Consultant in Design. Mr. Harmon, Jr., will be Research Consultant in Engineering.

**Roy Lewis Johnson** has been appointed manager of the Financial Department of General Electric's Lamp Division, with headquarters at Nela Park. Mr. Johnson, treasurer of the General Electric Supply Co. since July 1952, succeeds **Barrett A. Lindstrom**, who has been transferred to the Administration Department at Nela Park.

Crouse-Hinds Co., Syracuse, N. Y., has announced the retirement of **Charles H. Gurney**, manager of the company's New York Sales Division. Mr. Gurney's successor, **Arthur F. Uhrlandt**, will supervise a sales territory which encompasses New York State, Connecticut, northern New Jersey and western Vermont. Crouse-Hinds has also announced the appointments of **Richard F. Kidwell** as Regional Manager for metropolitan New York, and of **Charles Knox** as Divisional manager of the Philadelphia Division.

Appointment of **Donald D. Scarff** as manager of the General Electric Lamp Division's Puget Sound Sales District, with headquarters at **Seattle, Wash.**, has been announced. Mr. Scarff succeeds **L. R. Wilson**, who retired December 31, under the provisions of General Electric's pension plan, after 29 years of service with the company. Mr. Scarff for the past several years has had assignments in various phases of the Lamp Division's activities at Nela Park, and in the division's South Central Sales District, at Memphis, Tenn.

The firm of Bunston, Ltd., 2532 Yew St., Vancouver, B. C., with **Roy F. E. Bunston**, General Manager, has been appointed sales representative in Western Canada for the Abolite Lighting Division of Jones Metal Products Co.,

(*Continued on page* 14A)

**eye-insurance** for Peninsular Life Insurance Company,

Jacksonville, Florida

# Guth LITE-BLOX* TROFFERS

**It's Peninsular Life's business to think of the future. And they have chosen Guth Troffers!**

Just picture those inspiring lines of light in *any* office you plan or build. See how the troffers blend with the modern decor . . . how they appear to be custom-made for the setting. Notice how the even, low-brightness light softens every surface it strikes . . . even shiny steel files.

Guth Troffers fill the entire building with beauty and eye-ease. They create an atmosphere of efficiency . . . a pleasant place to work 8 full hours a day.

## PACKED WITH ADVANTAGES

**UNLIMITED LIGHT PATTERNS** —They form any design that can be made with standard 12" ceiling tiles!

**UNBROKEN LINES OF LIGHT** —Precision-built units align perfectly in arrow-like lines.

**CUSTOM-MADE LOOK** —Gleaming snap-on trim hides flange screws and "teebar gap" . . . adds a distinctive tailored appearance.

**PERFECT CORNERS** —Tile-Lites are used with troffers to make continuous light around corners.

**THE EXACT FOOT-CANDLES YOU NEED** —Use 1, 2, 3, or 4 lamps . . . 2′, 4′, 5′, 6′, or 8′ lamps . . . choose from 24 different sizes of standard, slimline or low-brightness types.

**EASIER INSTALLATION** —Complete units . . . ready to mount. One man can hang them! Wide-open space for wiring. Modular lengths that fit the job: 2′, 4′, 5′, 6′, and 8′. No trimming!

**LOW MAINTENANCE COST** —Hinged shield frame for easy relamping or cleaning. Slide-in reflectors are simple to remove and replace—no latches or nuts. Ballasts may be replaced without taking troffer down.

May we send you our Catalog 869-1?
Just drop us a line on your letterhead.

*TM—U. S. Pat. No. 2478822—others pending
**U. S. & Can. Pats. Pend.—TM Reg.

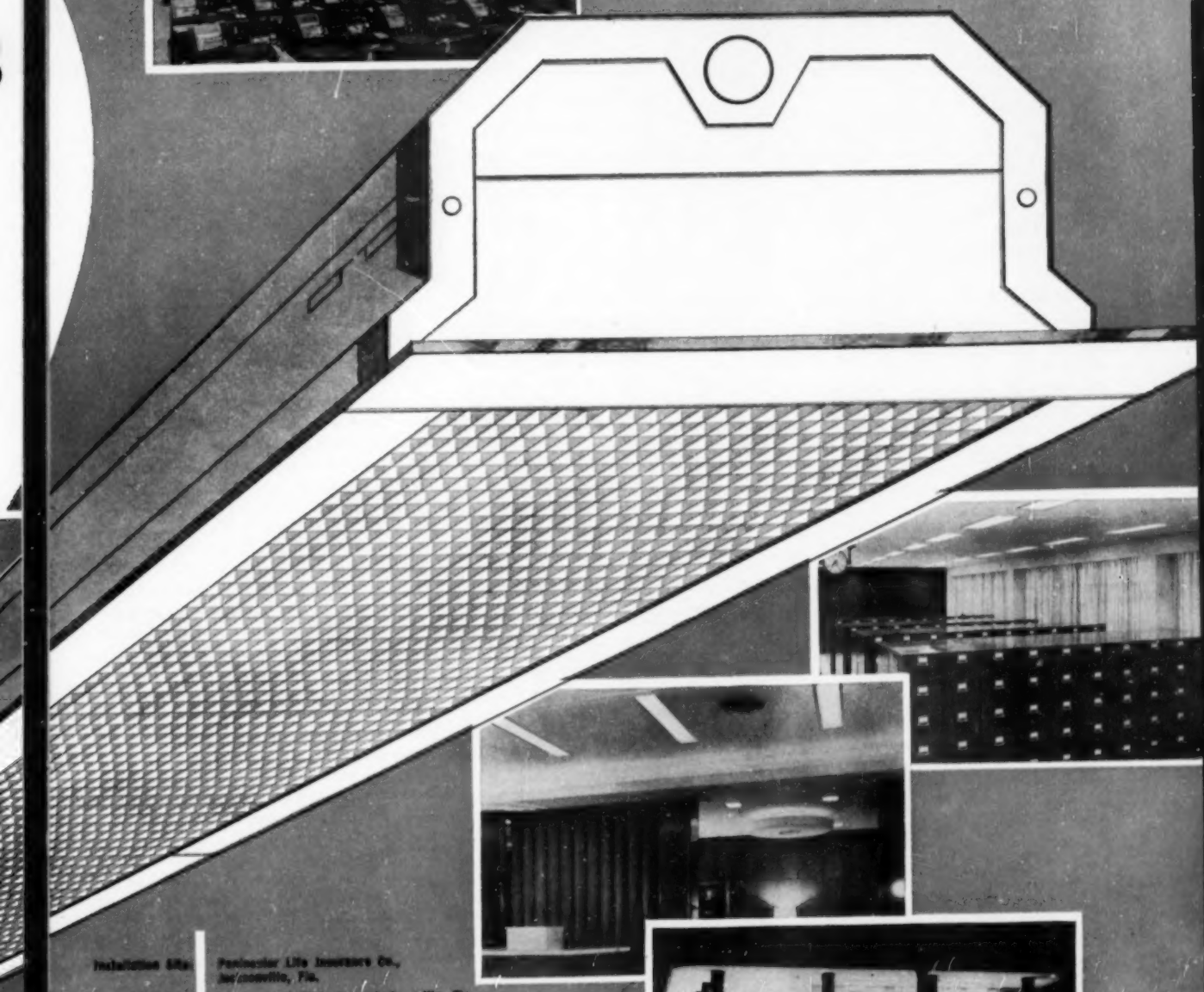
THE

## ANY BOTTOM YOU CAN NAME

*Select the type that goes with your motif:*

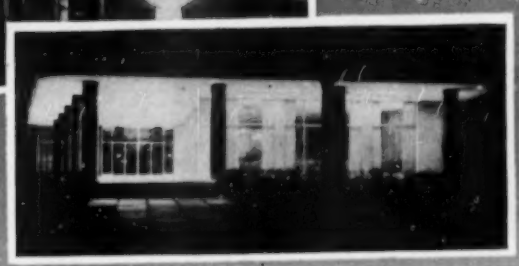
●**GRATELITE**** *, the new Louver-Diffuser for functional beauty and low-brightness, "velvetized" light (shown below)*

●PRISMATIC LENS ●GLOBOLITER
●CROSS BAFFLES ●ALBALITE GLASS
●CURVED PRISM LENS ●HINGED EGGCRATES
●OPEN TYPE ●FLUTEX GLASS









| | |
|---|---|
| Installation Site: | Peninsular Life Insurance Co., Jacksonville, Fla. |
| Architects: | Kemp, Dunch & Jackson, Jacksonville, Fla. |
| Consulting Engineer: | R. M. Garth, Jacksonville, Fla. |
| Electrical Contractors: | Caldwell & Joseph Electrical Co., Jacksonville, Fla. |
| Electrical Distributors: | Leslie E. Porter, Porter Lighting, Inc., Jacksonville, Fla. |

**EDWIN F. GUTH COMPANY** ST. LOUIS 3, MO.

*Leaders in Lighting since 1902*

(Continued from page 11A)

West Lafayette, Ohio. Through their branch offices in Calgary and Winnipeg, they serve the area of British Columbia, Alberta, Saskatchewan, Manitoba and the Ontario lakehead region.

**David N. Shefler**, president of Red Comet of Eastern Canada, Ltd., Montreal, has been appointed Canadian representative for Luminous Ceilings Inc. It will be handled through a new Acousti-Luminous Ceiling Division of that company for promotion of this ceiling.

**Professor Robert S. Green**, chairman of the department of welding engineering at the Ohio State University, has been named executive director of the University's Engineering Experiment Station. He succeeds **Professor Jacob R. Shank**, assistant director since 1938, who asked to be relieved as administrative head of the station to devote his full time to his professorship in the department of civil engineering. The change becomes effective April 1, 1954.

**Robert E. Jones**, of Sunbeam Lighting in Los Angeles, has been transferred to that company's North Pacific District, with headquarters at 444 Dexter Horton Bldg., Seattle, Wash. His position on the Board of Managers of the Southern California Section, I.E.S., is being filled by **Jake Hockenauer** of Benjamin Electric Mfg. Co.

The appointment of **Frank P. Schram** and **Harold R. Berkal** to the sales engineering staff of the Chicago office of Pittsburgh Reflector Co. has been announced. Both men will work out of the Chicago office, covering Northern Illinois, Wisconsin, Michigan and Indiana.

**David Forman** has been named Industrial Sales Manager of Radiant Lamp Corp., Newark, N. J. Mr. Forman has had wide experience in solving industrial illumination problems, and is one of the pioneers in the development of hard glass reflector type floodlights, spotlights, infra-red lamps and weatherproof PS-type lamps. Prior to joining the company in 1936, Mr. Forman was associated in various engineering and sales capacities with Arcturus Corp., Garod Radio Corp., and Splitdorf Radio Corp.

**Furna E. Lott**, who has operated out of Miami, as a manufacturers' agent for the past eight years, has been appointed to represent the Illuminating Division of the Miller Company, Meriden, Conn., in the state of Florida with the exception of Escambia, Okaloosa, Santa Rosa and Walton Counties.

Revere Electric Manufacturing Co., Chicago, announces the appointment of **Stanley M. Starr** as manager of street lighting sales. Mr. Starr formerly represented Revere in the Pittsburgh area, and was transferred to the Chicago office in an engineering capacity in 1953.

**Edward L. Peterson** has recently been appointed the Day-Brite representative for the San Diego and Southeastern California territory. His mailing address is Edward L. Peterson Co., 709 Bank of America Bldg., San Diego 1, Calif.

## OBITUARY

**Dr. Paul G. Agnew**, one of the pioneer leaders of standardization in the United States died at his home in New York City, January 8. He was 72.

Secretary of the American Standards Association until his retirement in December 1947, he served 28 years in this capacity, since its beginning in 1919.

Dr. Agnew was the first recipient of the Standards Medal, awarded annually to an outstanding contributor to voluntary standards. Known internationally for his leadership in promoting universally-accepted standards, Dr. Agnew helped lay the foundation of the International Federation of National Standardization Associations. In 1946, he helped in the formation of the present International Organization for Standardization.

## IT SEEMS TO ME

### Photo-Electric Brightness Meter

I was most interested in Karl Freund's article (October 1953 issue, I.E., pp. 524-526) on the design of a photo-electric brightness meter. This instrument will obviously be immensely valuable.

I think, however, he is wrong in his statement in the last paragraph that it is "the first commercial instrument for measuring the brightness of small areas that eliminates errors inherent in visual methods." There was such an instrument on the market in this country before the war. It was known as the "Expositron" and I came across it in the photo-engraving department of Messrs. E. S. & A. Robinson Limited of Bristol by whom I was then employed. It was used to measure the brightness of different areas in the copy in order to determine the exposure time when making screened separation negatives. The acceptance angle was, as far as I can remember, 1.5° and the area to be measured was viewed on a reflex ground glass screen. The instrument was used in two ways; to measure the required exposure (the units I believe were purely arbitrary) or, by means of a counter, to measure the total exposure time. Since the copy was illuminated by four arc lights whose brightness varied according to the variations on the mains, this method of measuring exposure by integrating the total light falling on the photo-cell of the instrument was much more accurate than the use of time alone.

I believe the firm which made this instrument went out of business at the outbreak of war. I enquired recently from my old firm and I understand the instrument is still in use. It was rather bulky and had to stand on a tripod, so that it could not readily be used in any of the ways which are described in Mr. Freund's article.—F. H. Murrell, *"Spinneys," Marlpit Lane, Redditch, Worcs., England.*

### Inspection Lighting

As the task of sorting small nuts and similar objects dealt with in the article "Applied Principles Solve Inspection Problem" (July 1953 I.E., pages 355, 356) happens to be a prototype of the aid lent to our vision by revealing shadows, I may be permitted to quote a different solution of the lighting problem which has been experimentally studied in 1927 in connection with psychotechnical research into the influence of good lighting on work efficiency. (H. Kuhn, Arbeitsleistung und Beleuchtung, Band VI, Heft 1 der Summlung "Deutsche Psychologie," Halle a S., 1927 Marhold). The solution is reproduced and discussed in my book "Shadow and Diffusion in Illuminating Engineering," pages 39, 40.

Contrary to the fully diffused high level lighting now called for, which eliminates shadows, as clearly perceptible in the illustration on page 355, directed side light has been applied with a view to producing deep "silhouette"-shadows with sharply defined outer edges. Thus the inspector looking almost perpendicularly down to the rapidly conveyed objects, is able to compare their contours by the length and width of their respective shadows. Such lighting can be arranged in various ways, *e.g.*, using inclined spotlights without specular reflection toward the inspector's eyes. A marked difference in shadows affords a quicker and safer discernment than the observation of the objects themselves under diffused light which even suppresses shadings without which the contours must appear hazy and blurred. Dr. Konrad Norden, *Caixa Postal, 3733, Rio de Janeiro, Brazil.*

(Continued on page 16A)

**Engineered by Specialists to meet your needs and specifications**

# Kopp lenses

EVERY Kopp Glass Lens is *designed* to meet some special set of conditions, *made* to meet exact specifications, and *checked* to assure complete compliance with all requirements.

The specialized knowledge needed for these operations has been developed through many years of specialization in the engineering and manufacturing of lenses. Kopp Laboratories are staffed and equipped to study your requirements and to develop lenses, color filters and roundels that accomplish your objectives. Manufacturing functions are performed by men skilled through long experience in the various operations.

This complete organization is at your service whenever you have a problem involving lighting glassware.

KOPP GLASS

**KOPP GLASS, Inc.**
SWISSVALE, PA.

IT SEEMS TO ME—*(Continued from page 14A)*

## Corrugated Glass Patent

Some of your readers may wish to be informed that in our brochure "Orrefors Lighting Fixtures," published towards the end of 1948, it was stated on page 3 that we owned the patent and exclusive sale rights all over the world of so-called double corrugated glass. This is not the fact, however, and we very much regret that owing to an oversight it was allowed to stand uncorrected in the brochure.

Through an agreement between Orrefors and Dr. Frederik Kurz, Nysätravägen 12, Lidingö, Sweden, we have acquired the rights concerning double-corrugated glass in Sweden (Patent No. 123583), Denmark (Patent No. 73896), Norway (Patent No. 79554), and Great Britain (Patent No. 563658), while Dr. Kurz owns the patent rights in all other countries. We are nevertheless entitled to export to all countries articles manufactured by Orrefors which fall under the protection — technical but not territorial — of this patent. The number of the patent which covers the manufacture of double-corrugated glass in the United States is 2610444.

We confirm at the same time that we do not own any rights whatever concerning Dr. Kurz' other patents. JOHAN BEVER, *AB Orrefors Glasbruk, Orrefors, Sweden.*

## BOOKS AND PAMPHLETS

*Books whose reviews are marked * are available for inspection at the I.E.S. Headquarters Office Technical Dept.*

***Colour in Theory and Practice** edited by H. D. Murray, published by Chapman and Hall Ltd., London, 1952; 373 7x9½-inch pages, 198 illustrations; price 70/– (approx. $10).

This British book is based on one published in 1939 by H. D. Murray and D. A. Spencer. The present volume is the work also of a panel of experts in the field of color: R. Donaldson, V. J. Francis, P. Holliday, R. G. Horner, N. Laycock, L. C. Thomson and G. T. Winch. The book deals with the physical properties of light, electro-magnetic wave theory, radiation phenomena, photochemical effects, photoelectric effect, absorption of light, electronic wave forms, color and chemical constitution, color vision, color matching and measurement, color description and specification, light sources, spectrophotometry, visual colorimeters, standard illuminants and artificial daylight, physical photometers and colorimeters, application of color, and color in nature.

This is a very comprehensive book with an extensive list of references at the end of each chapter. Appendices include 8 pages classifying natural and synthetic coloring materials and 18 pages of tables of interest to colorimetrists.

***Color Fundamentals** by Maitland Graves, published by McGraw-Hill Book Co., Inc., New York, 1952; 218 7x9½-inch pages, 95 illustrations (many in color); price $10.00.

In the words of the author, this book was written to "help the user of color understand these color aspects [physical, psychophysical, physiological, psychological and aesthetic] and their interrelationships in order that he may formulate a comprehensive, integrated concept upon which is based the power to use color intelligently and effectively." This is a non technical book on the science of color written by an art teacher. Topics treated are as follows: light (visible radiant energy), transmitters and reflectors of light (achromatic and chromatic), physical specification of colorants by spectrophotometry, colorant mixtures (subtractive and additive), effects of illuminants on colorant mixtures, colorant mixtures in photoengraving and printing, physiology and psychology of color sensation, color blindness, juxtaposition of colorants (optical illusions, color refraction, etc.), afterimages, Munsell system of color specification, color schemes (with 100 schemes shown in color) and a color "cabinet" for the artist. This book will provide engineers with an introduction to color from the viewpoint of the artist, and the artist with a simplified treatment of the physics and psychology of color.

***Principles of Color Photography** by Ralph M. Evans, W. T. Hanson, Jr., and W. Lyle Brewer; published by John Wiley & Sons, Inc., New York, 1953; 720 5½x8-inch pages, 317 illustrations; $11.00.

This is a highly technical book written by three Eastman Kodak scientists. Fifteen years in preparation, it is the first comprehensive volume to appear on this topic and includes much previously unpublished original work. There are 18 chapters covering Response of the Eye to Light in Simple Fields, Systems of Color Specification and Measurement, Responses to Light in Complex Fields, Visual Processes and Color Photography, Response of Photographic Materials, Color Response of Photographic Materials, Photographic Formation of the Color Image, Color Photographic Systems, Types of Dyes and other Colorants, Optical Characteristics of Colorants in Combination, Measurement of Density, Color Sensitometry, Analyses of Color-Sensitometric Characteristics, Reproduction Characteristics of a Hypothetical Subtractive Color Process, Duplicating, Copying a Color Photograph, Color Reproduction Theory for Additive Photographic Processes, and Color Reproduction Theory for Subtractive Photographic Processes.

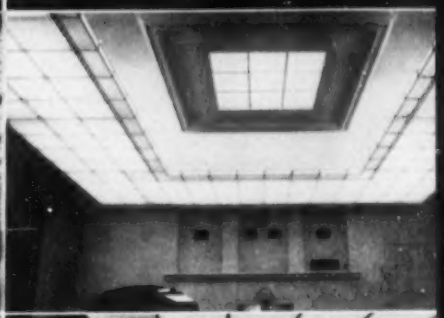
*Principles of Color Photographic* will be of value to anyone dealing extensively with color photography. The first three chapters (144 pages) will be of considerable interest also to illuminating engineers and psychologists interested in color vision.

**Residence Lighting Resource List** is now available free of charge from the I.E.S. Headquarters' Technical Department, 1860 Broadway, New York 23, N. Y. This 29-page bibliography was compiled by the I.E.S. Residence Lighting Committee especially for educators, home advisors and students of home lighting as a guide to current authoritative sources of associated study, research, development and recommended practice. Titles and a short description of each publication are classified according to the following categories: nature of light, light and vision, light sources, luminaires, lighting design principles, recommended lighting methods, housekeeping functions, architecture, interior design and furnishings, color, wiring, and visual and teaching aids.

**Cold Cathode Handbook**, a manual pertaining to cold cathode lighting, is available from the Fluorescent Lighting Association. Entitled "Handbook of Cold Cathode Fluorescent Lighting," the handbook was prepared by Bernard F. Greene, consultant to the association, and contains complete data on the electrical and photometric properties of the cold cathode lamp, and auxiliaries along with information on methods for using and installing this light source. The book contains 52 pages of text, charts, graphs and diagrams and installation photographs. Included are sections on general principles of lighting and lighting design. How the fluorescent lamp works, types of fluorescent lamps, cold cathode auxiliary equipment, photometric data, lamp life, lumen mainte-

*(Continued on page 19A)*

# *when the finest in lighting is specified...*

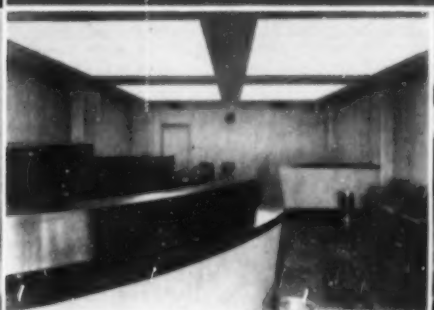


**Installations of Smithcraft Area Illumination the country over vary greatly as to size, pattern, shielding, periphery and shielding. And it's this *flexibility of design* that makes this advocated overall lighting system an important new architectural concept. All Smithcraft Area Illumination installations have these things in common: superb quality of illumination; functional integration with the building structure; ease and efficiency of installation and maintenance.**

*Reading from left to right, starting at top:*

The Mennen Company, Morristown, New Jersey
Owens-Corning Fiberglas Corp., Ashton, Rhode Island
Ford Motor Company, Dearborn, Michigan
Melbourne National Bank, Melbourne, Florida
Niagara Mohawk Power Corp., Syracuse, New York
Rawding Electric Company,
Beaver Falls, Pennsylvania
Texas Eastern Building, Shreveport, Louisiana
Mount Healthy-Saving and Loan Company,
Mt. Healthy, Ohio
Van Huffel Tube Corporation, Warren, Ohio
Florida Power and Light Company, Sanford, Florida

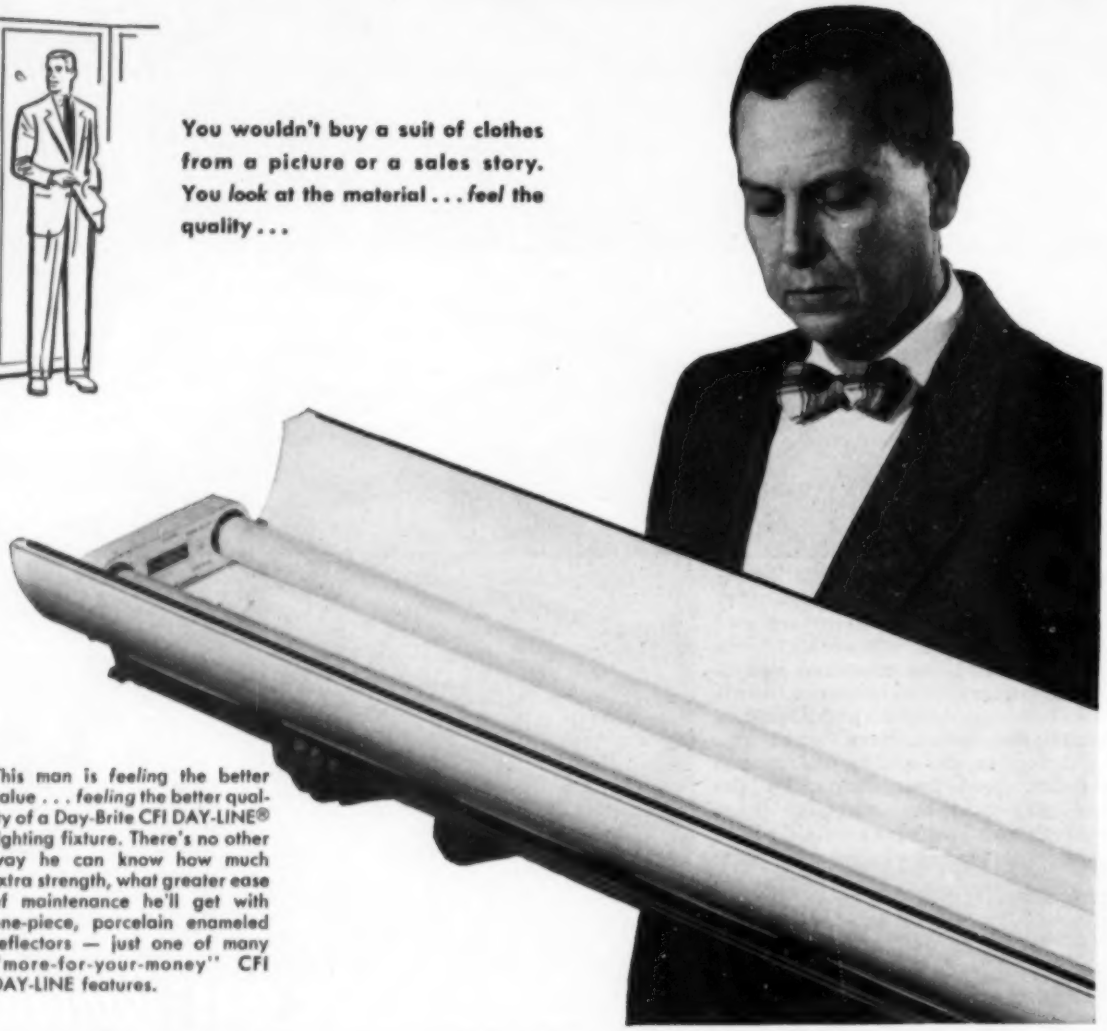
## *smithcraft* **area** *illumination*



...us to send you our new booklet giving further information on Smithcraft Area Illumination.

**Smithcraft**
**LIGHTING DIVISION**
CHELSEA 50, MASSACHUSETTS

**You wouldn't buy a suit of clothes from a picture or a sales story. You *look* at the material . . . *feel* the quality . . .**



This man is *feeling* the better value . . . *feeling* the better quality of a Day-Brite CFI DAY-LINE® lighting fixture. There's no other way he can know how much extra strength, what greater ease of maintenance he'll get with one-piece, porcelain enameled reflectors — just one of many "more-for-your-money" CFI DAY-LINE features.

# HOW TO PROTECT YOURSELF

## when you buy lighting fixtures

Buy lighting fixtures like you buy a suit of clothes. Look at them yourself . . . feel the value . . . feel the quality . . . feel the difference you can't always find in the sales stories.

Pictures, catalogs and sales stories are excellent ways to bring competitive lines of lighting fixtures to your attention.

But when you're ready to invest your money, *don't buy until you handle the fixtures yourself.* Don't buy until you're satisfied by your own inspection which fixture is *your* best buy.

We expect you to test the CFI DAY-LINE or any other Day-Brite fixture you're considering for plant lighting in exactly that way. We know from experience your judgment is the very best Day-Brite sales story we have.

LOOK AT THE CFI DAY-LINE®... FEEL THE DIFFERENCE... BEFORE YOU BUY!

DECIDEDLY BETTER
DAY-BRITE
Lighting Fixtures

Day-Brite Lighting, Inc., 5432 Bulwer Ave., St. Louis 7, Missouri.
In Canada: Amalgamated Electric Corp., Ltd., Toronto 6, Ontario.

423

(Continued from page 16A)

nance, economics of long life lamps, lamp operating temperature, direct current operation, stroboscopic effect, dimming, vibration, radio interference, color, illumination calculations, coefficients of utilization, dimensional data and how to install cove lighting and luminous ceilings. Cost of the book is $1.00 per copy, through the offices of the Fluorescent Lighting Association, Dept. 1, 100 West 42nd St., New York, N. Y.

A new edition of **See Your Home in a New Light**, a collection of light-conditioning recipes, has been prepared by the Lighting Laboratories of the General Electric Company. This second edition is described as completely revised and greatly expanded, and is available from the G. E. Lamp Division, Nela Park, Cleveland, Ohio.

The 1953-1954 edition of **I Want to Know About the Electric Industry**, an information booklet, said to be of unusual concept and form for an industry fact-book, has just been published by the Edison Electric Institute.

Subtitled "the answers to 28 questions frequently asked the Institute," the booklet consists primarily of single-page presentations of each question, with a brief answer and tabular and explanatory material for a more extended answer to the question. In most cases basic data are given in historically comparative form and the answers to the questions, collectively, provide a short, comprehensive story of electric industry operations, progress and relationship to the national economy.

The material in the booklet is industrywide in scope. Most of the basic national data is derived from the EEI's annual Statistical Bulletin and from various publications of the Federal Power Commission. The questions deal not only with such matters as "How does the United States rank in world production of electricity? and How fast is it moving in production and generating capacity?" but discuss as well more immediate topics such as "Who uses how much? What about electricity at home? Who owns the electric industry? Who produces and sells the greatest percentage of electricity?"

In addition to general coverage of industrial, commercial, farm and home use of electric power, such subjects as revenues and expenses, fuel consumption, steam plant and water power installations and ownership trends of generating installations are also discussed.

The booklet is available from the Edison Electric Institute, 420 Lexington Ave., New York 17, N. Y.

**Through History with Standards** is a 20-page booklet showing by cartoons and examples in text how standardization has come about for many products, measurements and services. Presented in a humorous vein, the booklet contains much information on the contributions that standards have made to the industries concerned. The booklet is available from the American Standards Association, 70 East 45th Street, New York 17, N. Y.

## NEW MEMBERS

At the meeting of the I.E.S. Council Executive Committee held in New York, N. Y. on January 14, 1954, the following were elected to membership. Names marked * are transfers from Associate Member grade.

ALABAMA CHAPTER

*Members:*
Easter, E. C., Alabama Power Co., Birmingham, Ala.
Lary, W. C., 2310 Broad St., Tuscaloosa, Ala.

*Associate Member:*
Robinson, J. C., 2066 Allendale Rd., Montgomery, Ala.

ARIZONA CHAPTER

*Member:*
Demaree, D. M., 128 N. 1st Ave., Phoenix, Ariz.

*Associate Members:*
Baldwin, W. D., A & B Lighting Co., Phoenix, Ariz.
Byers, J. R., Arizona Public Service Co., Phoenix, Ariz.
Pertofsky, M. J., Lighting & Lamps Inc., Phoenix, Ariz.

CAPITAL SECTION

*Member:*
*Downing, Jack, Westinghouse Electric Corp., Richmond, Va.

CAROLINAS SECTION

*Associate Members:*
Ege, J. H., Westinghouse Electric Corp., Raleigh, N. C.
Falkenberg, C. F., Biberstein Bowles & Meacham, Charlotte, N. C.
Hewson, H. M., Verdaray Corp., Charlotte, N. C.
Meador, J. T., Southern Electric Service Co., Inc., Charlotte, N. C.

CENTRAL NEW YORK SECTION

*Member:*
Taylor, D. W., N. Y. State Electric & Gas Co., Elmira, N. Y.

CHICAGO SECTION

*Members:*
*Orelove, A. E., Grayco Products, Chicago, Ill.
Rackley, C. E., Benjamin Electric Mfg. Co., Des Plaines, Ill.

*Associate Members:*
Berkal, H. R., Pittsburgh Reflector Co., Chicago, Ill.
Collyer, W. A., Hyland Electrical Supply Co., Chicago, Ill.
DuBroff, Warren, Hub Electric Co., Chicago, Ill.
Recher, G. D., 1438 W. North Shore Ave., Chicago, Ill.
Richards, W. D., Sola Electric Co., Chicago, Ill.
Stolley, C. A., Ragnar Benson, Inc., Chicago, Ill.

CLEVELAND SECTION

*Associate Members:*
Beesley, E. M., General Electric Co., Cleveland, Ohio.
Carlstroem, P. A., Sylvania Electric Products Inc., Cleveland, Ohio.
Hrivnak, Andrew, Jr., Ohio Edison Co., Massillon, Ohio.
Papp, L. C., Westinghouse Electric Corp., Cleveland, Ohio.
Toenjes, D. A., General Electric Co., Cleveland, Ohio.

CONNECTICUT SECTION

*Associate Member:*
Giannoni, G. J., John P. Legnos Associates, Newington, Conn.

FLORIDA CHAPTER

*Associate Members:*
Sanders, Julia B., Tampa Electric Co., Tampa, Fla.
Whipple, L. B., Florida Power Corp., St. Petersburg, Fla.
Whitfield, J. E., Jr., Appleton Electric Co., Clearwater, Fla.

GEORGIA SECTION

*Member:*
*Bythewood, R. C., Georgia Power Co., Atlanta, Ga.

*Associate Members:*
Brown, W. E., Graybar Electric Co. Inc., Atlanta, Ga.
Koen, J. H., Georgia Power Co., Atlanta, Ga.
Vawter, W. I., Graybar Electric Co., Atlanta, Ga.

INLAND EMPIRE CHAPTER

*Associate Member:*
Chapman, T. J., Line Material Co., Spokane, Wash.

MEXICO CHAPTER

*Associate Member:*
Martinez Vara, A., Metalicos y Anodizados, S. A., Mexico, D. F.

MICHIGAN SECTION

*Associate Member:*
Davis, C. W., City of Detroit, City Engineer Office, Detroit, Mich.

MID-SOUTH CHAPTER

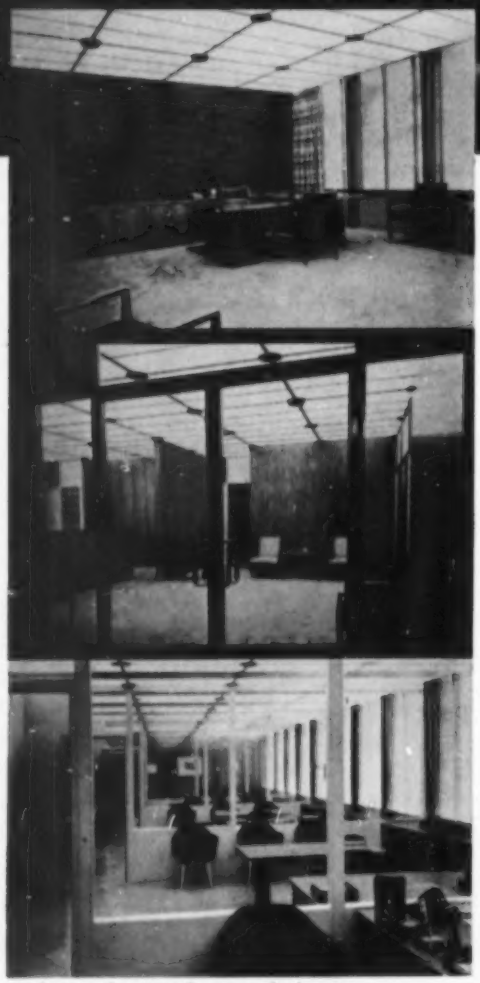
*Associate Member:*
Hays, G. A., 968 S. Cooper St., Memphis, Tenn.

*Student Members:*
Aftel, Harvey, Southern College of Optometry, Memphis, Tenn.
Aron, Howard, Southern College of Optometry, Memphis Tenn.
Bedsole, D. V., Southern College of Optometry, Memphis Tenn.
Boyles, H. D., Jr., Southern College of Optometry, Memphis, Tenn.
Bryant, R. J., Southern College of Optometry, Memphis, Tenn.
Coats, J. J., Southern College of Optometry, Memphis Tenn.
Coppedge, J. H., Southern College of Optometry, Memphis, Tenn.
Eure, S. B., Southern College of Optometry, Memphis Tenn.
Evans, W. L., Jr., Southern College of Optometry, Memphis, Tenn.
Gatten, W. H., Southern College of Optometry, Memphis Tenn.
Gordon, S. R., Southern College of Optometry, Memphis Tenn.
Hamilton, C. B., Southern College of Optometry, Memphis, Tenn.
Harman, W. L., Southern College of Optometry, Memphis, Tenn.
Hendrix, W. G., Southern College of Optometry, Memphis, Tenn.
Hill, B. J., Southern College of Optometry, Memphis, Tenn.
Langenfeld, R. P., Southern College of Optometry, Memphis, Tenn.
May, O. B., Jr., Southern College of Optometry, Memphis, Tenn.
Moore, Maurice, Southern College of Optometry, Memphis, Tenn.
Moorefield, L. J., Jr., Southern College of Optometry, Memphis, Tenn.

(Continued on page 36A)

# For Luminous Ceilings at Their Best—

# PLEXIGLAS



*Architects: Saarinen-Saarinen & Associates.*

Canadian Distributor: *Crystal Glass & Plastics, Ltd., 130 Queen's Quay at Jarvis Street, Toronto, Ontario, Canada.*

PLEXIGLAS is listed in Sweet's Architectural File, Section 6d/Ro.

Luminous ceilings with diffusing panels of PLEXIGLAS® provide highest quality lighting and clean, fixture-free appearance in offices, lobbies and corridors of this Engineering Staff building of a major motor car manufacturer. In addition, they conceal air ducts, and water pipes for sprinkler heads located inconspicuously below the diffusers.

Luminous ceilings are at their best in function and appearance when the all-important diffusers are PLEXIGLAS, because this Rohm & Haas Company acrylic plastic:

*. . . provides efficient, uniform diffusion of light.*

*. . . resists discoloration and breakage.*

*. . . is strong, light in weight, and dimensionally stable.*

*. . . can be formed at low cost to custom shapes.*

We will be glad to send you literature on the use of PLEXIGLAS for luminous ceilings and large-area fixtures.

CHEMICALS FOR INDUSTRY

**ROHM & HAAS COMPANY**

**WASHINGTON SQUARE, PHILADELPHIA 5, PA.**

*Representatives in principal foreign countries*

# SUSTAINING MEMBERS

**Acme Electric Corp.**
Cuba, N. Y. *J. A. Comstock*

**Advance Transformer Company**
1122 W. Catalpa Ave., Chicago 40, Ill. *A. E. Feinberg*

**Alabama Power Co.**
Birmingham, Ala. *George L. Morris*

**All Bright Electric Products Co.**
3917-25 N. Kedzie Ave., Chicago 18, Ill. *Max Klein*

**Aluminum Company of America**
Gulf Building, Pittsburgh 19, Pa. *C. Braglio*

**Amalgamated Electric Corp., Ltd.**
384 Pape Ave., Toronto, Ont., Canada *W. A. Dalrymple*

**American Concrete Corp.**
5092 N. Kimberly Ave., Chicago 30, Ill. *J. W. Lewis*

**American Fluorescent Corp.**
1234 N. Paulina St., Chicago 22, Ill. *William Rusnak*

**American Sterilizer Co.**
Erie, Pa. *Horace Wm. Alexander*

**Appleton Electric Co.**
1701-1729 Wellington Ave., Chicago 13, Ill. *Nils A. Tornblom*

**Arkansas Power & Light Co.**
Simmons National Bldg., Pine Bluff, Ark. *Max Sudduth*

**The Art Metal Co.**
1814 E. 40th St., Cleveland 3, Ohio *George E. Glatthar*

**Atlantic City Electric Co.**
1600 Pacific Ave., Atlantic City, N. J. *John B. Taylor*

**Benjamin Electric Mfg. Co.**
Des Plaines, Ill. *Benjamin S. Benson*

**Black & McDonald Limited**
200 King Street W., Toronto, Ont., Canada. *W. J. McDonald*

**Blue Ridge Glass Corp.**
P.O. Box 631, Kingsport, Tenn. *James Herbert*

**Board of Water and Electric Light Commissioners**
116 W. Ottawa St., P.O. Box 570
Lansing 3, Mich. *John D. Malnight*

**Boston Edison Co.**
39 Boylston St., Boston 12, Mass. *R. B. Brown, Jr.*

**Branham, Mareck & Duepner, Inc.**
7020 Walker St., St. Louis Park
Minneapolis 16, Minn. *Cecil H. Branham*

**British Columbia Electric Rwy. Co., Ltd.**
570 Dunsmuir St., Vancouver, B. C., Canada *H. N. Walters*

**Brockton Edison Co.**
36 Main St., Brockton 67, Mass. *W. A. Forbush*

**California Electric Power Co.**
P.O. Box 512, Riverside, Calif. *Robert W. Dowd*

**Calpa Products Co.**
5420-28 Paschall Ave., Philadelphia 4, Pa. *Paul C. Calissi*

**Cambridge Electric Light Co.**
Cambridge 39, Mass. *James L. Corrigan*

**Canadian General Electric Co., Ltd.**
212 King St., Toronto, Ont. *R. M. Love*

**Canadian Laco Lamps, Ltd.**
745 Guy St., Montreal, Que. *J. Thomas*

**Canadian Line Materials, Ltd.**
Postal Station H., Toronto 13, Ont., Canada *L. E. Messinger*

**Canadian National Exhibition Association**
Exhibition Park, Toronto, Ont. *H. E. McCallum*

**Central Hudson Gas and Electric Corp.**
50 Market St., Poughkeepsie, N. Y. *H. E. Dexter*

**Central Illinois Light Co.**
316 Jefferson Ave. S., Peoria 2, Ill. *W. F. Bolle*

**Central Illinois Public Service Co.**
607 E. Adams St., Springfield, Ill. *B. L. Palm*

**Central Louisiana Electric Co., Inc.**
P.O. Box 1096, Lafayette, La. *J. R. Gaugler*

**Central Maine Power Co.**
9 Green St., Augusta, Maine *Roland W. Hess*

**Central Power & Light Co.**
P.O. Box 2121, Corpus Christi, Texas *James M. Williams*

**Champion Lamp Works Div. of Consolidated Electric Lamp Co.**
600 Broad St., Lynn, Mass. *Ellery H. Raddin*

**Cincinnati Gas & Electric Co.**
Fourth & Main Sts., Cincinnati 1, Ohio *J. R. Hartman*

**City of Burbank, California Public Service Dept.**
164 W. Magnolia Boulevard, Burbank, Calif. *Ralph Foy*

**City of Glendale Public Service Dept.**
119 N. Glendale Ave., Glendale 6, Calif. *L. W. Grayson*

**City of Riverside Light Dept.**
P.O. Box 826, Riverside, Calif. *A. J. Kennedy*

**City of Seattle, Dept. of Lighting**
1015 Third Ave., Seattle 4, Wash. *P. C. Spowart*

**City of Tacoma, Light Division**
402 City Hall, Tacoma 2, Wash. *Roy H. Weston*

**The Cleveland Electric Illuminating Co.**
75 Public Square, Cleveland 1, Ohio *R. C. Hienton*

**Clyde Porcelain Steel Corp.**
2211 Birdseye St., Clyde, Ohio *W. F. White*

**C. W. Cole & Co., Inc.**
320 E. 12th St., Los Angeles 15, Calif. *Russell W. Cole*

**Colonial Premier Corp.**
466 W. Superior St., Chicago 10, Ill. *Richard Weis*

**Columbia Electric & Mfg. Co.**
Box 2180, Spokane, Wash. *Walter A. Toly*

**Commercial Light Co.**
841 W. Washington Blvd., Chicago, Ill. *Michael R. Fine*

**Commonwealth Edison Co.**
72 W. Adams St., Chicago 90, Ill. *G. K. Hardacre*

**Compco Corporation**
2251 W. St. Paul, Chicago 47, Ill. *Lawrence H. Wrobel*

**Connecticut Light & Power Co.**
P.O. Box 2010, Hartford 1, Conn. *Robert G. Ely*

**Consolidated Edison Co. of N. Y., Inc.**
4 Irving Place, New York 3, N. Y. *C. Miller*

**Consolidated Gas, Electric Light & Power Co. of Baltimore**
100 W. Lexington St., Baltimore 1, Md. *M. C. Albrittain*

**Consumers Power Co.**
212 Michigan Ave. W., Jackson, Mich. *D. E. Karn*

**Consumers Public Power District**
1452 25th Ave., Columbus, Nebr. *W. H. Sinks*

**Continental Electrical Construction Co.**
3540 Southport Ave., Chicago 13, Ill. *Leo W. Witz*

**Corning Glass Works**
Corning, N. Y. *A. S. Tylor*

**Coyne Electrical School, Inc.**
500 So. Paulina St., Chicago 7, Ill. *John Hanan*

**Crouse-Hinds Co.**
Syracuse 1, N. Y. *A. H. Clarke*

**Crouse-Hinds Co. of Canada, Ltd.**
7 Labatt Ave., Toronto, Ont. *F. R. Jeffery*

**Curtis Lighting, Inc.**
6135 W. 65th St., Clearing Station
Chicago 38, Ill. *Darwin Curtis*

**Curtis Lighting of Canada, Ltd.**
195 Wicksteed Ave., Leaside, Toronto 12, Ont. *H. L. Wright*

**Cutler Light Manufacturing Co.**
2026-28 N. 22nd St., Philadelphia 21, Pa. *Robert T. Cutler*

**Dallas Power & Light Co.**
1506 Commerce St., Dallas 1, Texas *W. G. Moore*

**Day-Brite Lighting, Inc.**
5401 Bulwer St., St. Louis 7, Mo. *D. J. Biller*

**The Dayton Power & Light Co.**
25 No. Main St., Dayton, Ohio *H. S. Nonneman*

**Dazor Manufacturing Corp.**
4483 Duncan Ave., St. Louis 10, Mo. *P. L. Read*

**Delaware Power & Light Co.**
600 Market St., Wilmington 99, Del. *W. A. F. Pyle*

**Dept. of Water & Power, City of Los Angeles, Bureau of Power & Light**
Box 3669, Terminal Annex, 207 So. Broadway
Los Angeles 54, Calif. *Ivan L. Bateman*

**Detroit Edison Co.**
2000 Second Ave., Detroit 26, Mich. *L. E. Taylor*

**Detroit Electrical Contractors Association**
940 Book Building, Detroit 26, Mich. *Carl J. Schoeninger*

**Detroit Steel Products Co.**
2250 E. Grand Blvd., Detroit 11, Mich. *W. Clifton Randall*

**E. I. duPont de Nemours & Co., Inc. (Fabrics & Finishes Div.)**
Wilmington 98, Del. *S. W. Quisenberry*

**E. I. duPont de Nemours & Co., Inc. Polychemicals Dept. Development and Service Section**
Wilmington 98, Del. *Henry Peterson*

**Duquesne Light Co.**
435 Sixth Ave., Pittsburgh 19, Pa. *G. W. Ousler*

**Duray Fluorescent Mfg. Company**
3518 W. Montrose Ave., Chicago 18, Ill. *Ludwig Dannenberg*

**Duro Test Corp.**
2521 Hudson Blvd., North Bergen, N. J. *James L. Cox*

**Eastern Fixture Co., Inc.**
170 Vernon St., Boston 20, Mass. *Louis Gilman*

(*Continued on page 22A*)

(*Note:* Names of Official Representatives appear in italics.)

**East Side Metal Spinning & Stamping Corp.**
1301 Elizabeth Ave., W., Linden, N. J.
*M. A. Kremer*

**Ebasco Services, Inc.**
2 Rector St., New York 6, N. Y. *P. D. Brooks*

**Efengee Electrical Supply Co.**
949 W. Chicago Ave., Chicago 22, Ill. *Lee Mirus*

**Electrical Information Publications, Inc.**
20 N. Carroll St., Madison, Wis.
*Lewis E. Johnston*

**Electric Supply Corporation**
701 W. Jackson Blvd., Chicago 6, Ill.
*G. M. Marks*

**Electrical Products Corporation**
1100 North Main St., Los Angeles 12, Calif.
*L. A. Rice*

**Electrical Testing Laboratories, Inc.**
79th St. & East End Ave., New York 21, N. Y.
*W. F. Little*

**Electro Silv-A-King Corporation**
2000 West Fulton St., Chicago 12, Ill.
*C. I. Schneider*

**Electrolier Mfg. Company, Ltd.**
5849 Boyer St., Montreal, Que., Canada
*John Issenman*

**Englewood Electrical Supply Co.**
5801-03 So. Halsted St., Chicago, Ill. *Ray O'Leary*

**Enterprise Electric Co.**
6507 Euclid Ave., Cleveland, Ohio *William S. Fell*

**Esty Manufacturing Company**
1231 W. Monroe St., Chicago 6, Ill.
*Ben Trossman*

**Ever-Brite Products Corp.**
1629 Milwaukee Ave., Chicago 47, Ill.
*Jack Lipschultz*

**Fitchburg Gas & Electric Light Co.**
537 Main St., Fitchburg, Mass. *A. G. Neal*

**Florida Power & Light Co.**
Box 3100, Miami 30, Fla. *R. J. Bradley*

**Fluorescent Equipment & Mfg. Co.**
5105 Cowan Ave., Cleveland 4, Ohio
*Leonard S. Freeman*

**Fluorescent Fixtures of Calif.**
3320 18th St., San Francisco 10, Calif.
*Ernest O. Anders*

**Fluores-O-Lite Co.**
Evans Terminal, No. Broad St., Hillside, N. J.
*Meyer H. Silverman*

**The Fostoria Pressed Steel Corp.**
Fostoria, Ohio *E. L. Bates*

**H. A. Framburg & Co.**
3320-28 Carroll Ave., Chicago 24, Ill.
*Stanley A. Framburg*

**The France Mfg. Co.**
10325 Berea Rd., Cleveland 2, Ohio *E. L. Walter*

**The Frankelite Co.**
1425 Rockwell Ave., Cleveland 14, Ohio
*Dave Frankel*

**Franklin Design Service**
**Division of Safeway Stores, Inc.**
4th & Jackson Sts., P.O. Box 660
Oakland 4, Calif. *T. E. Rinehart*

**The Frink Corporation**
27-01 Bridge Plaza North
Long Island City, N. Y. *Theo. J. Brassel, Jr.*

**Fullerton Manufacturing Corp.**
17 Chestnut St., South Norwalk, Conn.
*Lawson Fullerton*

**Gallagher-O'Brien Electric Co., Inc.**
915 W. North Ave., Chicago 22, Ill.
*Frank A. Gallagher*

**Garden City Plating & Mfg. Co.**
1750 No. Ashland Ave., Chicago 22, Ill.
*G. G. Harney*

**General Electric Co., Apparatus Dept.**
River Works, 920 Western Ave.
West Lynn, Mass. *W. J. Fleming*

**General Electric Co., Lamp Dept.**
Nela Park Cleveland 12, Ohio *Willard C. Brown*

**General Electric Supply Company**
**A Division of General Electric Distributing Corp.**
1260 Boston Ave., Bridgeport 9, Conn.
*W. W. Booth*

**General Fireproofing Co.**
Dennick Ave., Youngstown, Ohio *J. A. Saunders*

**General Lighting Products Co.**
468 Frelinghuysen Ave., Newark 5, N. J.
*Nathan H. Eglowstein*

**General Outdoor Advertising Co., Inc.**
515 So. Loomis St., Chicago, Ill. *C. E. Freeland*

**The Georgia Power Co.**
Electric Building, Atlanta 1, Ga.
*C. M. Wallace, Jr.*

**Gibson Manufacturing Co.**
1919 Piedmont Circle N. E., Atlanta, Ga.
*R. R. Gibson*

**Gill Glass & Fixture Co.**
Amber & Tioga Sts., Philadelphia 34, Pa.
*C. A. Gill*

**Gillinder Brothers, Inc.**
Erie & Liberty Sts., Port Jervis, N. Y.
*J. Fletcher Gillinder*

**Globe Lighting Products Co., Inc.**
1710 Flushing Ave.,Brooklyn 6, N. Y.
*Isidor Rosenblatt*

**Graybar Electric Co., Inc.**
420 Lexington Ave., New York 17, N. Y.
*Raymond C. Kinney*

**Great Northern Mfg. Co.**
4221 W. Harrison St., Chicago 24, Ill. *D. J. Epp*

**Guardian Light Company Inc.**
301 Lake St., Oak Park, Ill. *W. S. Akely*

**Gulf States Utilities Co.**
Box 2951, Beaumont, Texas *Clarence Barron*

**The Edwin F. Guth Co.**
2615 Washington Ave., St. Louis 3, Mo.
*Fred E. Guth*

**The Hankins Container Co.**
3044 W. 106th St., Cleveland 11, Ohio
*Ray T. White*

**Hartford Electric Light Co.**
266 Pearl St., Hartford 3, Conn. *Victor Ouellette*

**Hawkins Electric Co.**
1447 Washington Blvd., Chicago 7, Ill *R. R. Hill*

**Holdenline Co.**
2301 Scranton Rd., Cleveland 13, Ohio
*H. E. Ingraham*

**Hollywood Wholesale Electric Co.**
6820 Romaine St., Hollywood 38, Calif.
*James H. Diffenwierth*

**Holophane Company, Inc.**
342 Madison Ave., New York 17, N. Y.
*H. L. Logan*

**Holophane Company, Limited**
150 The Queensway, Toronto 14, Ont.
Canada. *Frank T. Groome*

**House-O-Lite Corporation**
2430 S. Ashland Ave., Chicago 8, Ill.
*Jack R. Stone*

**Hub Electric Company**
2219 W. Grand Ave., Chicago 12, Ill.
*I. M. Fixman*

**Hubbard and Company**
6301 Butler St., Pittsburgh 1, Pa. *C. C. Warne, Jr.*

**Hydro-Electric Power Comm. of Ontario**
620 University Ave., Toronto, Ont. *R. L. Hearn*

**Hyland Electrical Supply Co.**
700 West Jackson Blvd., Chicago, Ill.
*Charles K. Lambka*

**Illinois Power Co.**
134 East Main St. (L, Box 511B),
Decatur 70, Ill. *Allen Van Wyck*

**Illuminating Engineering Co.**
2347 E. Nine Mile Road, Hazel Park, Mich.
*Bert C. Pretzer*

**Interstate Power Co.**
1000 Main St., Dubuque, Ia. *R. C. Halcombe*

**Iowa Electric Light & Power Co.**
Box 351, Cedar Rapids, Ia. *Sutherland Dows*

**Iowa-Illinois Gas & Electric Co.**
United Light Bldg., Davenport, Iowa
*John M. Hollingsworth*

**Iowa Power and Light Co.**
312 Sixth Ave., Des Moines 3, Iowa
*N. Bernard Gussett*

**Iowa Public Service Co., East Div.**
400 Commercial St., Waterloo, Iowa
*C. R. Wagoner*

**Iowa Public Service Co., Sioux City Division**
P.O. Box 778, Sioux City 4, Iowa *C. R. Tracy*

**Jefferson Electric Co.**
Bellwood, Ill. *L. Maurer*

**Jersey Central Power & Light Co.**
501 Grand Ave., Asbury Park, N. J. *D. L. Douglas*

**Jeryl Lighting Products Inc.**
42 West Cermak Rd., Chicago, Ill.
*Charles Meyerson*

**Joleco Corporation**
2513 Baldwin St., St. Louis, Mo. *George Ledbetter*

**Jones Metal Products Co.**
West Lafayette, Ohio *H. Boyer*

**Joslyn Mfg. & Supply Co.**
3700 So. Morgan St., Chicago 9, Ill. *J. H. Fahey*

**Kansas City Power & Light Co.**
P.O. Box 679, Kansas City 10, Mo.
*John M. Arthur, Jr.*

**Kansas Gas & Electric Co.**
P.O. Box 208, Wichita, Kans. *H. W. Hobson*

**The Kayline Company**
2480 E. 22d St., Cleveland 15, Ohio *M. A. Eskins*

**Kelso-Burnett Electric Co.**
223 W. Jackson Blvd., Chicago 6, Ill.
*Sigmund A. Hollinger*

**Kerrigan Iron Works, Inc.**
1033 Herman St., Nashville, Tenn. *G. E. Daniels*

**Keystone Electric Manufacturing Co.**
2228-36 E. Tioga St., Philadelphia 34, Pa.
*Leonard M. Siegel*

**The Kirlin Company**
3435 E. Jefferson Ave., Detroit 7, Mich.
*Ivan Kirlin*

**Kopp Glass, Inc.**
Swissvale, Pa. *F. C. Ashe*

**Morris Kurtzon, Inc.**
1420-30 So. Talman Ave., Chicago 8, Ill.
*David Koch*

**The La Salle Lighting Products, Inc.**
145 Seneca St., Buffalo 3, N. Y.
*Richard C. Piper, Jr.*

**The Leeds & Northrup Co.**
4901 Stenton Ave., Philadelphia 44, Pa.
*Dr. R. C. Machler*

**Libbey-Owens-Ford Glass Co., Plaskon Division**
2112-24 Sylvan Ave., Toledo, Ohio
*Dr. M. H. Bigelow*

**Light Control Company**
3217 Casitas Ave., Los Angeles 26, Calif.
*Stanley E. Lindahl*

(Continued on page 24A)

# ultra-shallow fluorescent luminaires from MITCHELL

minimum maintenance

maximum lighting efficiency

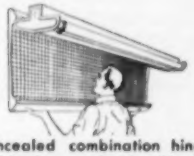
ultra-modern styling

MITCHELL THINLINE

## Choice of 4 and 8 foot lengths in 2 and 4 lamp models — All lamp types available

New "Thinline" answers the need for high-efficiency illumination, coupled with attractive styling. Outstanding advantages include: ultra-shallow contour provides pleasing, streamlined installation; special translucent "Evenglo" plastic sides and louver give higher light transmission, yet provide tremendous hiding power and diffusion for desirable low surface brightness; superior louver design with proper 45°/45° cutoff conceals lamps from all normal viewing angles. Advance styling, unusually low maintenance factor and high lighting efficiency make the new MITCHELL "Thinline" Luminaires outstanding values in commercial fluorescent lighting.

Note the ultra-shallow contour. When flush-mounted, the luminaire presents a beautiful streamlined appearance.



Concealed combination hinge and latch on each side of luminaire permit easy removal of louver from either side.

New Rapid-Start units are available; they slash maintenance cost by eliminating expense of replacing starters.

"Evenglo" translucent extruded Polystyrene side panels provide desirable uniform low surface brightness.

*Write for complete descriptive brochures describing the new MITCHELL Ultra-Shallow "Thinline," "Polaris" and "Modernizer" Luminaires*

MITCHELL POLARIS

The new ultra-shallow "Polaris" luminaire incorporates all the fine features described at right, with Penticore prismatic glass shielding delivering a light transmission factor of 85%, with excellent diffusing quality. The combination of high light output and the low surface brightness of the "Evenglo" sides and Penticore Glass shield creates ideal, harmonious lighting for the finest commercial interiors.

MITCHELL MODERNIZER

This is the new ultra-shallow luminaire designed to meet the requirements of large commercial installations where high-efficiency lighting and *exceptional* low cost are primary considerations. The luminaire features a V-spine design which provides a highly reflective surface to increase down-light intensity. The 8-foot units feature special "tandem" design (two 4-foot units with one 8-foot body channel) to save installation time and assure perfect alignment in continuous rows.

where quality counts — SPECIFY MITCHELL

**MITCHELL MANUFACTURING CO.**

2525 N. Clybourn Ave., Chicago 14, Ill., Dept. 3-B

In Canada: Mitchell Mfg. Co., Ltd., 19 Waterman Ave., Toronto

(Continued from page 22A)

**Lighting Products, Inc.**
2259 W. Park Ave., Highland Park, Ill.
*D. E. Dunne*

**Lightolier Co.**
11 East 36th St., New York 16, N. Y. *H. Stollnitz*

**Line Material Co., Division of McGraw Electric Co.**
800 North 8th St., Milwaukee 1, Wis. *M. C. Harsh*

**Litecontrol Corp.**
36 Pleasant St., Watertown 72, Mass.
*Paul H. Lamson*

**Lithonia Lighting Products Co., Inc.**
Lithonia, Ga. *Robert J. Freeman*

**Louisiana Power & Light Co.**
142 Delaronde St., Station "A,"
New Orleans, La. *C. L. Osterberger*

**Luminator, Inc.**
120 N. Peoria St., Chicago 7, Ill.
*Albert L. Arenberg*

**Luminous Ceilings Inc.**
2500 West North Ave., Chicago 47, Ill.
*Louis Rosenstein*

**Lynn Gas & Electric Co.**
90 Exchange St., Lynn, Mass. *James A. Cook*

**Macbeth Corp.**
P.O. Box 950, Newburgh, N. Y. *Norman Macbeth*

**Main Electric Company**
741 Milwaukee Ave., Chicago, Ill.
*William Kamin*

**Major Equipment Company Inc.**
4609-19 Fullerton Ave.,Chicago, Ill.
*Ross O. Major*

**Malden Electric Co.**
157 Pleasant St., Malden, Mass.
*Warren K. Lewellen*

**Markel Electric Products, Inc.**
145 E. Seneca St., Buffalo 3, N. Y.
*Morris L. Markel*

**Markstone Manufacturing Co.**
2460 W. George St., Chicago, Ill. *Martin Schwartz*

**Marvin Manufacturing Co.**
3071 E. 12th St., Los Angeles 23, Calif.
*Carl O. Anderson*

**La Cie Martineau Electrique Ltee.**
24 rue du Roi, Quebec, Canada *Henri Martineau*

**Metalcraft Products Co., Inc.**
Masher & Lippincott Sts., Philadelphia 33, Pa.
*Nathan Bloom*

**Metropolitan Edison Co.**
412 Washington St., Reading, Pa.
*T. O. McQuiston*

**Metropolitan Electrical Supply Co.**
20 N. Jefferson St., Chicago 6, Ill. *Fred Pedrigi*

**Midwest Chandelier Co.**
15th & Gentry Sts., No. Kansas City 16, Mo.
*Sidney Lefkovitz*

**The Miller Co.**
Meriden, Conn. *G. W. Beals*

**Mississippi Glass Co.**
88 Angelica St., St. Louis 7, Mo. *Reed Muir*

**Mississippi Power Co.**
Gulfport, Miss. *R. M. Shearer*

**Mississippi Power & Light Co.**
Lampton Building, Jackson, Miss. *B. M. Davis*

**Mitchell Manufacturing Company**
2525 Clybourn Ave., Chicago 14, Ill.
*Bernard Mitchell*

**Mitchell Manufacturing Co., Ltd.**
19 Waterman Ave., Toronto 13, Ont.
*J. E. Landers*

**Modern Light Company**
7809 Maplewood Industrial Court,
Maplewood 17, Mo. *J. E. Baker*

**Modern Light & Equipment Co.**
3812 S. Wabash Ave., Chicago, Ill.
*M. L. Offenberg*

**Moe-Bridges Corp.**
1415 Illinois Ave., Sheboygan, Wis.
*Frank J. Marriet*

**Moe Light, Inc.**
700 Oak St., Fort Atkinson, Wis. *Stanley Warner*

**Monroe Electric Co.**
157 W. Ontario St., Chicago 10, Ill. *Albert Kahn*

**Montana-Dakota Utilities Co.**
831 Second Ave. So., Minneapolis 2, Minn.
*W. L. Hayes*

**The Montana Power Co.**
40 East Broadway, Butte, Mont. *D. J. McGonigle*

**Mountain States Power Co.**
236 Lyon St., Albany, Ore. *A. T. Peterson*

**Municipal Light and Power Dept.**
City of Pasadena, California, 302 City Hall
Pasadena 1, Calif. *T. M. Goodrich*

**Mutual Sunset Lamp Mfg. Co., Inc.**
540 Empire State Bldg., New York 1, N. Y.
*Morris Thau*

**The Narragansett Electric Co.**
49 Westminster St., Providence 1, R. I.
*C. R. Broadhead*

**National Chemical & Manufacturing Co.**
**Luminall Paint Div.**
3617 So. May St., Chicago 9, Ill.
*John Marshall Ziv*

**New Bedford Gas & Edison Light Co.**
693 Purchase St., New Bedford, Mass.
*W. S. Fenstermacher*

**New Orleans Public Service, Inc.**
317 Baronne St., New Orleans, La. *S. L. Drumm*

**New York State Electric & Gas Corp.**
62 Henry St., Binghamton, N. Y.
*Earle C. Edwards*

**Niagara Mohawk Power Corp.**
300 Erie Blvd. W., Syracuse 2, N. Y.
*R. H. Stratton*

**Northern Electric Co., Ltd.**
1600 Notre Dame St., West, Montreal, Quebec
*A. G. V. Smith*

**Northern Indiana Public Service Co.**
5265 Hohman Ave., Hammond, Ind.
*J. C. Sackman*

**Northern Light Company**
1657 No. Water St., Milwaukee 2, Wis.
*Fred Cramer*

**Northern States Power Co.**
Minneapolis 2, Minn. *Carl T. Bremicker*

**Ohio Edison Co. (Akron Div.)**
Akron 8, Ohio *C. L. Dunn*

**The Ohio Power Co.**
301-315 Cleveland Ave., S. W.
Canton 2, Ohio *R. W. Osterholm*

**The Ohio Public Service Co.**
P.O. Box 6058, Cleveland 1, Ohio *C. L. Dunn*

**Oklahoma Gas & Electric Co.**
Box 1498, Oklahoma City 1, Okla. *E. W. Gray*

**Omaha Public Power District**
720 Electric Bldg., Omaha 2, Neb. *E. E. Schwalm*

**Pacific Gas & Electric Co.**
245 Market St., San Francisco 6, Calif.
*O. R. Doerr*

**Pacific Power & Light Co.**
522 Public Service Bldg., Portland 4, Ore.
*C. A. Root*

**Peerless Electric Limited**
5585 Fullum, Montreal 36, Que. *L. A. Van Duzer*

**Wm. Penn Fluorescent Light Mfg. Co.**
1429 So. 23rd St., Philadelphia 46, Pa.
*Pat Pedicone*

**Pennsylvania Electric Co.**
222 Levergood St., Johnstown, Pa.
*Howard E. Ross*

**Pennsylvania Power Co.**
19 E. Washington St., New Castle, Pa.
*P. G. Dingledy*

**Pennsylvania Power & Light Co.**
901 Hamilton St., Allentown, Pa. *J. M. Stedman*

**The Perfeclite Company**
1457 E. 40th St., Cleveland, Ohio
*Joseph L. Jaffe, Jr.*

**Philadelphia Electric Co.**
1000 Chestnut St., Philadelphia 5, Pa.
*R. G. Rincliffe*

**Philadelphia Electrical & Mfg. Co.**
1228-36 N. 31st St., Philadelphia 21, Pa.
*R. A. Manwaring*

**Phoenix Glass Co.**
Monaca, Pa. *D. G. Cameron*

**Pierce Electric Co.**
367 W. Adams St., Chicago 6, Ill. *John H. Pierce*

**Pittsburgh Corning Corp.**
1 Gateway Center, Pittsburgh, Pa.
*Robert W. McKinley*

**Pittsburgh Plate Glass Co.**
Grant Bldg., Pittsburgh 19, Pa. *R. B. Tucker*

**Pittsburgh Reflector Co.**
403-411 Oliver Bldg., Pittsburgh 22, Pa.
*H. C. Zinsmeister*

**Portland General Electric Co.**
Electric Bldg., Portland 5, Ore. *T. W. Fitch*

**The Potomac Edison Co.**
55 E. Washington St., Hagerstown, Md.
*C. D. Lyon*

**Powerlite Devices, Limited**
1876 Davenport Rd., Toronto 9, Ont.
*M. B. Hastings*

**Progressive Products Co., Inc.**
6615 Milwaukee Ave., Chicago 31, Ill.
*E. George Goddard*

**Pryne & Co., Inc.**
P.O. Box 698, Pomona, Calif. *Roger W. Holston*

**Public Service Co. of Colorado**
900 Fifteenth St., Denver, Colo. *G. B. Buck*

**Public Service Co. of Indiana, Inc.**
1000 E. Main, Plainfield, Ind. *Robert McMurray*

**Public Service Co. of Oklahoma**
Box 201, Tulsa 2, Okla. *C. N. Robinson*

**Public Service Electric & Gas Co.**
80 Park Place, Newark 2, N. J. *H. P. J. Steinmetz*

**Puget Sound Power & Light Co.**
860 Stuart Bldg., Seattle 11, Wash.
*Frank McLaughlin*

**Quadrangle Mfg. Co.**
32 So. Peoria St., Chicago 7, Ill.
*Dwight E. Worrell*

**Quaker City Electric Mfg. Co.**
2810 East Pacific St., Philadelphia, Pa.
*Reuben Haberman*

**Quebec Hydro-Electric Commission**
107 Craig St., West, Montreal, Que.
*Paul E. Poitras*

**Quebec Power Company**
P. O. Box 1607, Quebec, Que. *Jean Saint-Jaques*

**Rambusch Decorating Co.**
40 W. 13th St., New York 19, N. Y.
*Edward Rambusch*

**Revere Electric Mfg. Co.**
6009-17 N. Broadway, Chicago 40, Ill.
*Murray J. Whitfield*

**Revere Electric Supply Company**
2501 W. Washington Blvd., Chicago 12, Ill.
*Arthur Peterson*

**Rochester Gas & Electric Corp.**
89 East Ave., Rochester 4, N. Y. *L. C. Twichell*

**Rockland Light & Power Co.**
Nyack, N. Y. *D. S. Schaab*

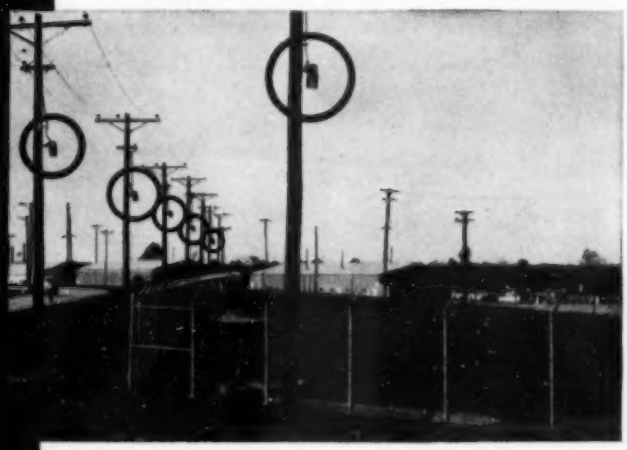
**Rohm and Haas Co.**
222 W. Washington Sq., Philadelphia 5, Pa.
*W. T. Reedy*

(Continued on page 27A)

U. S. ATOMIC ENERGY COMMISSION'S 200,742 ACRE SAVANNAH RIVER PLANT

# LIGHTS MILES of HIGHWAY, FENCE and PARKING AREAS with Pemco LUMINAIRES

SENTINELS that guard the fence lines of this secret installation are Pemco's protective lighting units illustrated here. Specially designed, they throw a blinding glare in the faces of intruder or saboteur, on one side, sheath the other side in protective darkness. Can be positioned horizontally or vertically (as shown).

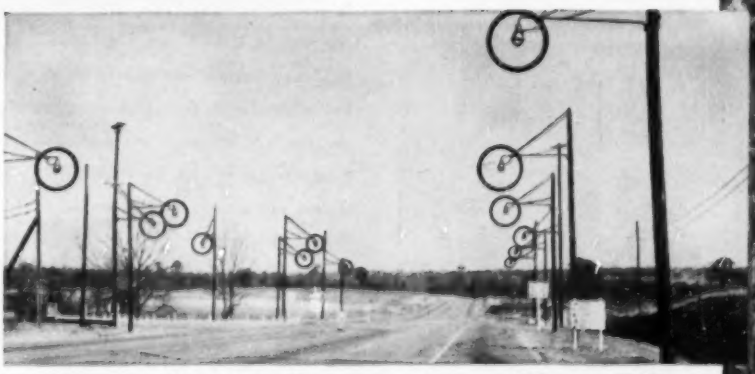


INTERIOR ROADS at Savannah River are lit by Pemco's modern street lighting units (shown here with special-built fire alarm indicator). Pemco luminaires conform to E.E.I. NEMA standards, and as a result of Pemco pioneering through the years in the field of exterior lighting, offer efficient, low-cost operation combined with maximum flexibility.

Pemco was privileged to work on the entire lighting plan for this vast Savannah River establishment in conjunction with du Pont Company engineers.

Pemco's Engineering Department will be pleased to help you with your lighting problem. Also available is the Pemco Catalog of Lighting Equipment No. 90.

Write for your copy — no obligation!

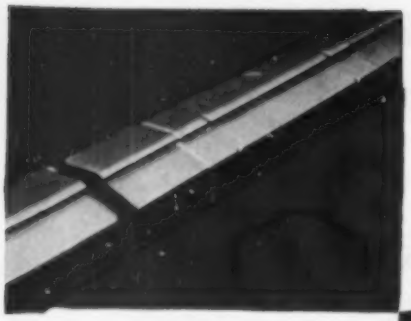


Pemco

**PHILADELPHIA ELECTRICAL & MFG. CO.**

**1200 NORTH 31st ST., PHILA. 21, PA.**

America's Pioneer Street Lighting Manufacturer Still under its original name *Offices in Principal Cities*



**LOCKED IN PERFECT ALIGNMENT**

Uni-Race sections slide into a firm telescopic union with coupler forming a rigid channel that will not distort (even before screws are added) and assures perfect fixture alignment.

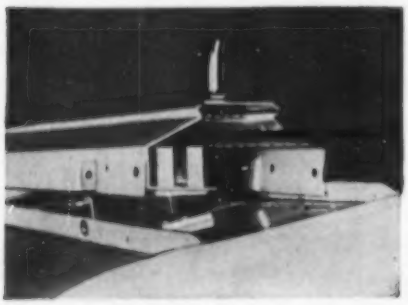
THE NEW

# ortho-77

Reg. U. S. Pat. Off. Applied For

**RIGID CHANNEL ANCHOR**

Light in weight, readily accessible and easily mounted, the Uni-Race provides a rigid channel anchor for all Ortho-77 models. Being machined to exceptional tolerances, it automatically provides for exact fixture spacing.



**PLUG-IN SOCKET**

Ortho-77 units are wired to a Plug-In Socket which makes contact with a receptacle in the Uni-Race when fixture is closed. Fixture becomes completely dead when open, and being wired in parallel circuits, does not disturb other fixtures when removed.

## WITH UNI-RACE

Acclaimed by lighting experts everywhere as "ushering in a new era in fluorescent fixture design"; the spectacular new Ortho-77 by Gibson is an entirely new concept of fixture design. Incorporated for the first time on any fluorescent fixture are a multitude of features that simplify installation, provide position alignment and spacing and give greater fixture rigidity. Now without tools and in a matter of minutes you can change fixtures instead of ballasts... raise lighting levels from two to four light or vary the levels as conditions demand... install fixtures at intervals automatically spaced and fill in quickly and easily as needed. Contractors have claimed as much as 50% saving in installation time with the Ortho-77 which means that you, the user, can install this revolutionary fixture incorporating the new Uni-Race, "V" type integrated construction, simplified plug-in wiring and many other features at no greater cost than a conventional installation. See it at your jobber today or write for bulletin Ort-101 for complete information.

**GIBSON** *Manufacturing Co.*

**1919 Piedmont Circle, N.E.** **Atlanta, Georgia**

(Continued from page 24A)

**Ruby Lighting Corp.**
1212 S. Olive St., Los Angeles 15, Calif.
*Albert Jassim*

**Ruby-Philite Corp.**
32-02 Queens Blvd., Long Island City 1, N. Y.
*Louis Phillips*

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1007 Arch St., Philadelphia 7, Pa. *T. W. Lauer*

**Ryall Electric Supply Co.**
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**The Safety Car Heating & Lighting Co.**
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*Roy E. Dahlin*

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*George R. Atchison*

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# Can't rust out! no cracks or crevices . . . no place for rust to get a foothold . . . seamless, one-piece housing with unbroken surface of "Life-Time" Porcelain Enamel!

# No service breaks due to humidity!

poor lamp-starting eliminated . . . electric contacts protected from corrosion . . . light-reducing dirt sealed out

Benjamin "Vapor-Tite" Units make it possible to provide modern fluorescent lighting for locations with moisture-laden atmospheres. They are specifically built to combat the corrosive effects of such humid workplaces as textile mills, laundries, bottling plants, food processing operations, etc. A solid armor of porcelain enamel defies humidity, steam, dirt and vapors. This is the "Life-Time" surface that cannot wear, scratch, become dull, deteriorate or corrode because it is literally "glass fused to steel".

In addition to the humidity-defying features described above, this unit is equipped with the patented Benjamin "Springlox" Lampholder... famous for "easy-in, easy-out" lamp servicing and completely safe operation in humid atmospheres. After 1,000 hours in 95% humidity at 95° F., and after 400 hrs., under a continuous salt spray, "Springlox" was still in operation! Get up-to-date information on fluorescent lighting that defies humidity... ask for Bulletin VT. Benjamin Electric Mfg. Co., Dept. I, Des Plaines, Ill.

7R-261

available with this exclusive Benjamin "Springlox" Lampholder for two or three 48" bi-pin or single-pin fluorescent lamps.

BENJAMIN

"VAPOR-TITE"

Sold exclusively through electrical distributors

A Product of Benjamin Electric Mfg. Co., makers of famous Benjamin and Leader Line Lighting Equipment and Sound Signals for Industry, Institutions and Commerce.

# 19% more starts on rapid-start lamps with Sola Constant Wattage Ballasts

RAPID CYCLING TEST: In Sola's laboratory an accelerated-start life test (½ minute on, 1½ minutes off) was conducted using the rapid-start fluorescent lamps of three different manufacturers. Lamps of each brand were operated from both the Sola Constant Wattage Ballast and another leading make of ballast. The photograph shows two remaining lighted lamps, Sola ballasted, which finally failed after 67,560 starts. The results of the test are summarized in the table below.

**RAPID CYCLING TEST, 106v.**

| RAPID-START LAMP MAKE | LIFE SPAN SUPERIORITY OF SOLA BALLASTED LAMPS |
|---|---|
| Brand "A" Lamp | 46.7% |
| Brand "B" Lamp | 14.7% |
| Brand "C" Lamp | 9.7% |
| Average All Lamps | 19% |

Ease of starting rapid-start lamps, and length of lamp life from starts, is proportional to the open circuit ballast voltage. Sola Constant Wattage Ballasts have a higher open circuit voltage (300v) from the lamp to the starting aid for positive starting. They are completely safe due to their isolated secondary circuit design . . . listed by Underwriters . . . and CBM Certified.

Repeated tests in the laboratory, and performance on actual installations show that rapid-start fluorescent lamps operating from Sola Constant Wattage Ballasts form an almost perfect lighting system: long lamp life with frequent starts or continuous operation, and lumen output constant within ±2% regardless of line voltage variations from 106-130v.

The many dollars saved on relamping more than absorb the 5c per year price premium of Sola Constant Wattage Ballasts over ordinary ballasts.

**Saves dollars in maintenance for only 5 pennies a year**

**SOLA** *Constant Wattage* **BALLASTS**

**WRITE FOR BULLETIN 3B-FL-191**

Transformers for Constant Voltage • Fluorescent Lighting • Cold Cathode Lighting • Mercury Vapor Lighting • Luminous Tube Signs
SOLA ELECTRIC CO., 4633 W. 16th Street, Chicago 50, Illinois, Bishop 2-1414 • NEW YORK 35: 103 E. 125th St., TRafalgar 6-6464
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CLEVELAND 15: 1836 Euclid Ave., Prospect 1-6400 • KANSAS CITY 2, MO.: 406 W. 34th St., Jefferson 4382 • Reps. in Other Principal Cities

**in our plazas,**
parking areas, shopping centers and drive-ins
NEWARK AIRPORT
P & K Double and Single Tapered Elliptical Arm type standards installed here have 25 foot mounting heights, TB-2 Transformer Bases and 12 foot arms. Four 20 foot floodlight poles with twin projector assemblies are also installed. They are in perfect harmony with Newark Airport's recently modernized appearance and efficiency.

# the P&K story

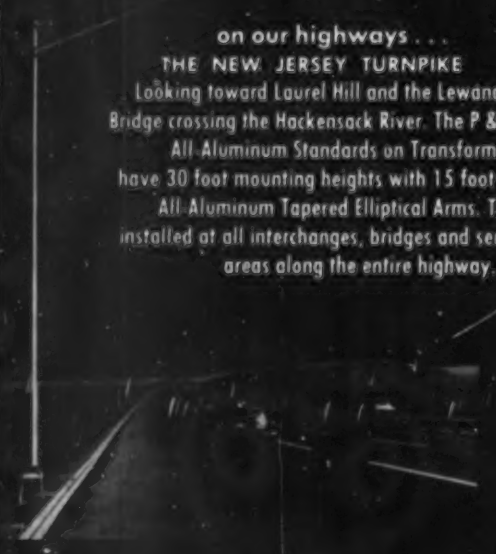
**in our communities . . .**
LEVITTOWN, PENNSYLVANIA
Scheduled for completion by the end of 1954, Levittown, Pa. will be the state's tenth largest city! Its streets will feature modern, efficient lighting provided by more than 4,000 P & K All-Aluminum Standards and Brackets: 20 foot pendant type with P & K Tapered Elliptical Lighting Arms.

**P & K ALL-ALUMINUM STANDARDS AND BRACKETS ARE PRODUCED IN DESIGN AND TYPE TO MEET *EVERY* ROAD, HIGHWAY, AREA OR FLOOD LIGHTING REQUIREMENT.**
They are always the wisest investment for both efficiency and economy:

- Much lighter weight for easy handling and low cost installation
- Negligible rate of corrosion for longest service life
- No painting means initial and year-after-year saving
- Easily salvaged and re-used in event of knockdown

WRITE FOR LATEST P & K CATALOG . . . and use the P & K planning and advisory services without obligation.

**on our highways . . .**
THE NEW JERSEY TURNPIKE
Looking toward Laurel Hill and the Lewandowski Bridge crossing the Hackensack River. The P & K All-Aluminum Standards on Transformer bases have 30 foot mounting heights with 15 foot All-Aluminum Tapered Elliptical Arms. They are installed at all interchanges, bridges and service areas along the entire highway.

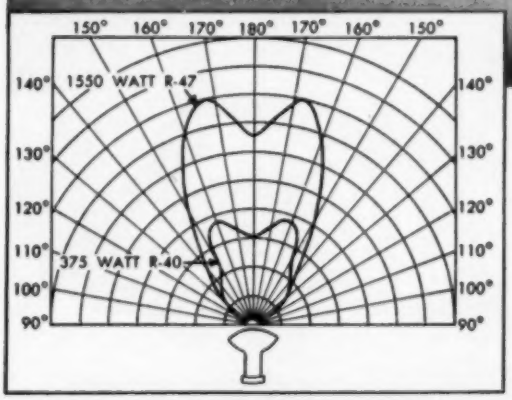


**Pfaff & Kendall**
84 Foundry Street
Newark 5, New Jersey

# Sylvania's Powerful New

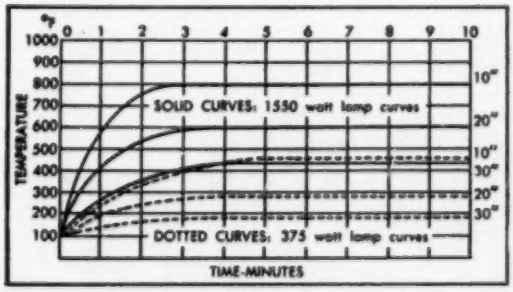
# INFRARED LAMP

## *Opens New Fields in Heat Processing!*




**Comparison of Angular Radiation Distribution**

**The two curves show a comparison of energy concentration of Sylvania's 1550-watt lamp against a 375-watt lamp. Readings were taken on a 2-foot radius. Note greater radiation of 1550-watt lamp over larger area.**




**Comparison of Temperature Levels**

**The above graph shows a comparison between temperature levels reached with Sylvania 1550-watt lamps and 375-watt lamps on .035 inch thick cold rolled steel placed 10, 20, and 30 inches from a 3 x 3 lamp bank.**

## *Delivers 3 times more radiation per square inch than conventional Infrared Lamps*

PROVIDING a wattage density much higher than ever before available for infrared lamps (36 watts per square inch) Sylvania's powerful new lamp now opens up an entirely new field of applications plus new economies in infrared commercial drying, baking, and heating.

This improved lamp is equipped with 2 separate filaments and may be operated at three different wattages (650, 900, and 1550) thus permitting close control of infrared output.

### Rugged and durable

Made of Vycor glass, the bulb is highly resistant to thermal shock and is unaffected by spattering liquids during operation.

Designed with a built-in gold reflector, which maintains 90 to 95% of its initial reflectivity, the lamp projects useful heat over an angle of approximately 120°.

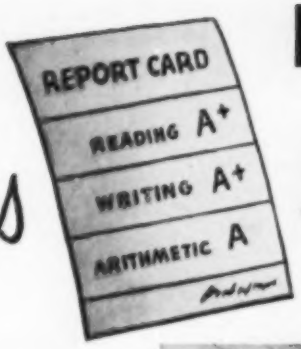
For further technical information concerning the amazing performance and adaptability of this latest Sylvania achievement, write to: Sylvania Electric Products Inc., Dept. 4L-3502, 1740 Broadway, New York 19, N. Y.

# SYLVANIA

**LIGHTING • RADIO • ELECTRONICS • TELEVISION**

In Canada: Sylvania Electric (Canada) Ltd.
University Tower Bldg., St. Catherine Street, Montreal, P. Q.

# BETTER LIGHTING assures better learning




**MEYERS PARK HIGH SCHOOL**
**Charlotte, N. C.**

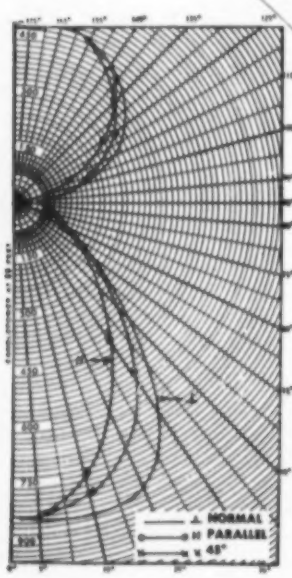
*Architects-Engineers:*
J. N. Pease & Company
Charlotte, N. C.

*Distributor:*
General Electric Supply Corporation
Charlotte, N. C.

*Electrical Contractor:*
Austin Electric Company
Charlotte, N. C.

**Using Garcy SL5030-8-430 ma (Louvered fixtures for two 96", T-12 Slimline lamps)**

Illustration shows GARCY SLN5030-8 "VISUALIER" for Slimline lamps . . . Also available in 4' units for fluorescent or slimline lamps, individual mounting or continuous runs. Four lamp matching fixtures also available.




***thousands of schoolrooms have been improved by GARCY'S "VISUALIER"***

Schoolroom lighting installations, once completed, have a way of staying on for many, many years. It is doubly important, therefore, to obtain the right fixture in the first place. Garcy's Visualier is eminently qualified. Lighting efficiency far exceeds I.E.S. and A.I.A. school lighting specifications . . . as to light utilization, light distribution, shielding and low surface brightness. And of equal importance, high level lighting efficiency can be readily maintained. The large louver cells are easily cleaned from the floor with a brush or vacuum. All-metal construction means no breakage or warping. Detailed literature and E.T.L. data sent on request.

*New Garcy Lighting Equipment Catalog Now Available*

# GARCY

GARCY lighting equipment

**GARDEN CITY PLATING & MFG. CO.**
**1760 North Ashland Avenue**
**Chicago 22, Ill.**

***Gives you All the Plus quality you can receive in Fluorescent Lamp Ballasts!***

**ADVANCE TRANSFORMER CO.**

Cable Address "ADTRANS"

2950 N. WESTERN AVE., CHICAGO 18, ILLINOIS, U.S.A.

INSTALLATION: State Savings Bank, Hartford, Conn.
ARCHITECT: R. B. O'Connor & W. H. Kilham, Jr., New York City, N. Y.
LIGHTING ENGINEERING BY: R. Cooper, Baldwin Stewart Electric Co., Hartford, Conn.
ENGINEER: Kaiser, Muller & Davies, New York City, N. Y.
NEW BANKING AREA: 36'-3" x 48'.
CEILING HEIGHT: 12'.
FIXTURES: Litecontrol No. 9034 3-lamp recessed fixtures, using Holophane No. 9030 and No. 9031 lenses.
LAMPS: Each fixture has two standard cool white, and one de luxe warm white lamp.
SPACING: 6' x 9'.
OVER-ALL INTENSITY: 42 footcandles average in service. On tellers' desk plates, 46 footcandles average in service.
*Submitted in contest by: Edward Cole, Hartford Electric Light Co.*

1st PRIZE

# *Prize Lighting Job* PAYS DIVIDENDS

## *. . . at Hartford State Savings Bank*

FIVE hundred new depositors selected this light, attractive lobby the *smart* place to do their banking . . . since it was relighted with ingeniously modified *standard* LITECONTROL fixtures. And so did the Connecticut section of the Illuminating Engineering Society, for they awarded it first prize in a recent lighting contest.

Problem here was to illuminate the new banking area (rear with low ceiling) in a modern distinctive manner . . . yet preserve the architectural tone of the old area (front with 24-foot ceiling).

*Planned Lighting by Litecontrol* provides standard fixtures that balance light intensity in both areas. Cool white and warm white fluorescent lamps blend to match the incandescent light from chandeliers. Note color quality of walls appears uniform throughout. While even illumination eliminates need for local light sources at tellers' cages.

You, too, can plan a better lighting installation at *standard fixture costs* — with your local LITECONTROL man.

LC

**LITECONTROL** *Fixtures*

**KEEP UPKEEP DOWN**

LITECONTROL CORPORATION, 36 Pleasant Street, Watertown 72, Massachusetts

DESIGNERS, ENGINEERS AND MANUFACTURERS OF FLUORESCENT LIGHTING EQUIPMENT DISTRIBUTED ONLY THROUGH ACCREDITED WHOLESALERS

***IF YOU SPECIFY OR BUY FLUORESCENT FIXTURES:***

# Here is why General Electric believes you should insist on series ballasts for 96T12 lamps

**Several years ago,** our engineers studied the merits of the series-type ballast circuit for operating the 96T12 lamp at 425 ma. It showed real possibilities for economy, both in ballast cost and size. With concentrated efforts, a series ballast design for this lamp was perfected. Then for the first time, a series-type ballast circuit meeting all lamp requirements and giving full rated lamp life was made available to you.

**Actually,** there was nothing basically new about the series-type ballast. As early as 1940, our engineers had studied such a circuit. As new lamps were made available over the years, the series ballast was investigated time and again. However, prior to the 96T12 lamp, the potential savings of the series ballast circuit had been discarded because no way had been found to meet lamp operating requirements.

**During those years** the lead-lag ballasting circuit was widely used for the various types of lamps then available. Naturally, this type of ballast gained wide acceptance in the lighting industry as the standard of ballast quality.

**After the 96T12 lamp** was introduced, a series ballast was developed which proved to be the best ballasting tool for this important new lamp. However, there was real hesitancy about accepting a series ballast for the 96T12 because in the past, a lead-lag ballast had been found superior for other lamps.

**We felt compelled** to face this challenge and advocate the series ballast for the 96T12 lamp because, everything considered, we believe it is the best ballasting tool for that lamp—giving equivalent performance in accordance with lamp specifications and offering a very substantial saving in cost and size.

**The results** are now known throughout the lighting industry. Millions of series ballasts for operation of 96T12 lamps at 425 ma have been furnished to the industry in the last three years by ballast manufacturers. And because series ballasts for this lamp are inherently 20% less costly—even more millions of dollars in basic ballasting cost have been saved for fluorescent lighting users.

**It will continue** to be our policy to use our engineering know-how and detailed knowledge of lamp requirements to produce and promote the sale of the very best ballast or selection of ballasts for every type of lamp. Whether lead-lag, series, or trigger-start, in our sincere best judgment, they will always represent the best ballast design to meet lamp and industry requirements. General Electric Company, Schenectady 5, New York. 401-4

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(*Continued from page* 19A)

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(*Continued on page* 38A)


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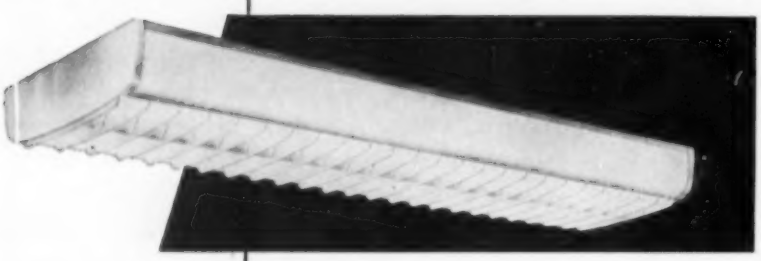

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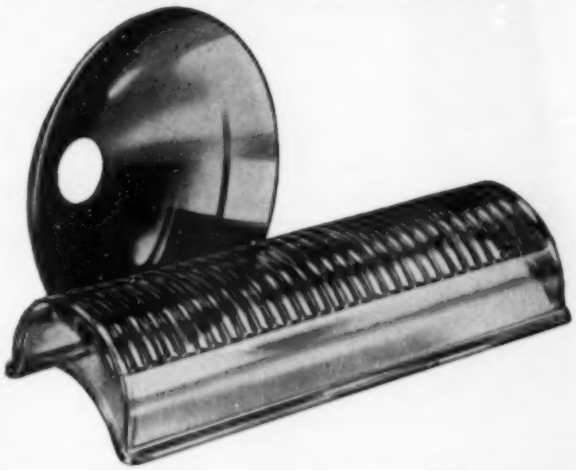

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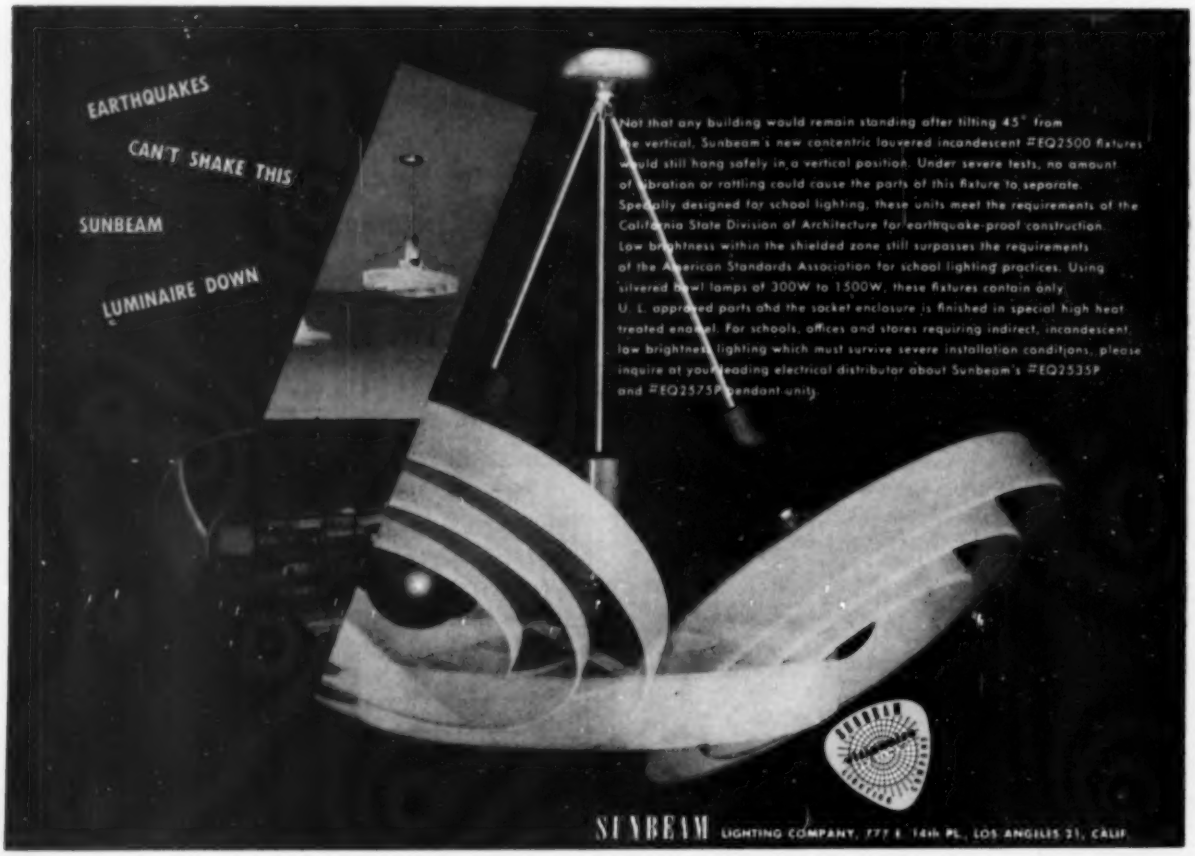
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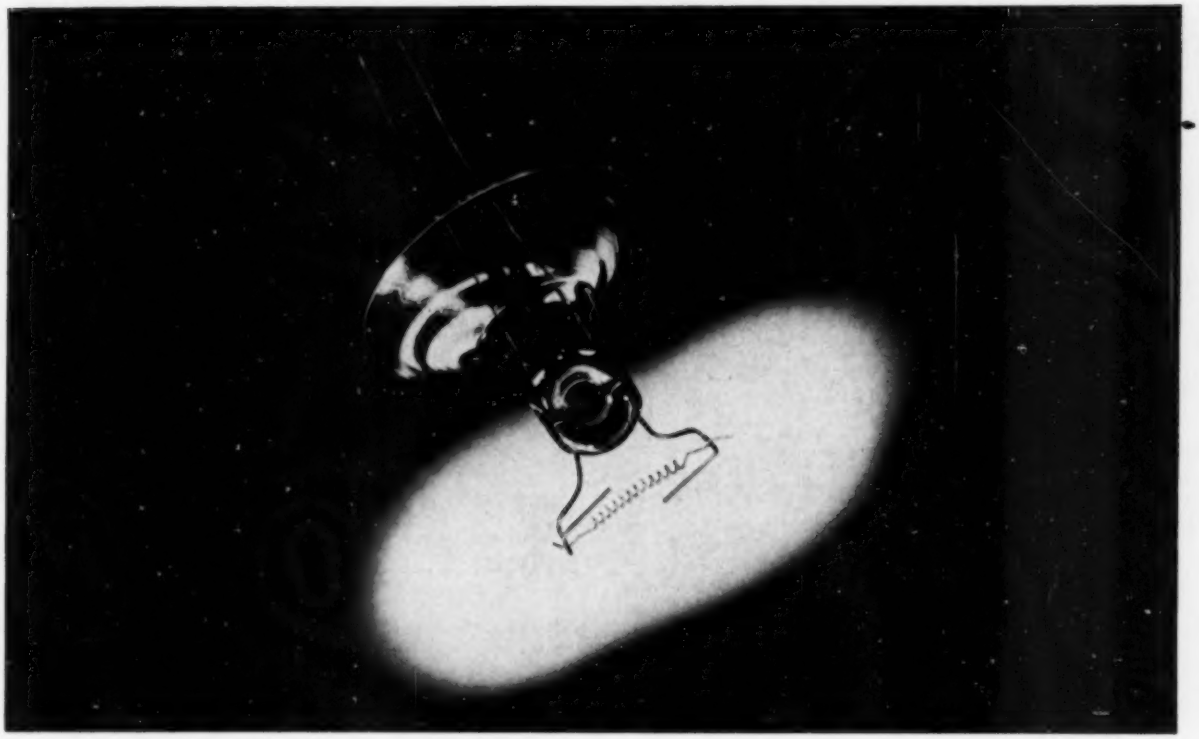

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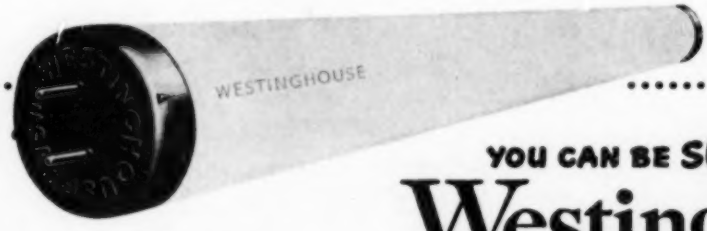


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